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Economic Impact Analysis of a Trihalomethane Regulation for Drinking Water. MCL of THM at 0.10 Milligrams/Liter for Large Water Systems

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ECONOMIC IMPACT ANALYSIS OF A TRIHALOMETHANE REGULATION FOR DRINKING WATER

U.S. Environmental Protection Agency
Office of Water Supply
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This document presents the national economic impact of a proposed amendment to the Interim Primary Drinking Water Regulations which will be the first phase of a program for trihalomethane control. A critical part of the impact is the cost to individual water systems and increased costs on a per capita basis. Therefore, as much attention has been directed to these measures as to total national costs.

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ECONOMIC IMPACT ANALYSIS OF A TRIHALOMETHANE REGULATION FOR DRINKING WATER

MCL OF THM AT 0.10 MILLIGRAMS/LITER FOR LARGE WATER SYSTEMS

Submitted to:

U.S. Environmental Protection Agency
Office of Water Supply
Washington, D.C.

by

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INTRODUCTION

During the last year, the Office of Water Supply at the Environmental Protection Agency has focused special attention on developing regulations for organic contaminants such as trihalomethanes in drinking water supplies. A significant component of this process has been estimating the national costs of adding the necessary treatments for the control of trihalomethane contamination. The purpose of this document is to present the national economic impact of a proposed amendment to the Interim Primary Drinking Water Regulations which will be the first phase of a program for trihalomethane control. A critical part of the impact is the cost to individual water systems and increased costs on a per capita basis. Therefore, as much attention has been directed to these measures as to total national costs.

There are several elements involved in developing the cost estimates for the regulation as it has been formulated. These are noted below and are covered in the separate sections which follow.

- The first section, entitled Analytic Structure, describes:

  --the regulatory criteria. These are the parameters defined by the regulation; they determine which water systems are covered.

  --the number of community water systems and the populations they serve. These represent the suppliers of drinking water to year-round residents, some of which will be affected by the regulation. Those affected by the maximum contaminant level are divided into three size categories for this analysis.

  --available treatment alternatives. These are the treatments which water systems can implement to comply with the regulation.

--profile of systems' response to the regulation. The treatments which systems are likely to select are determined on the basis of their relative costs, the severity of the contamination, and existing treatment practices.

- The Costs of the Regulation include:

  --national costs of the regulation. Based on all of the above elements, these are estimates of the costs to comply at the national level for all systems affected by the regulation.

  --costs to a typical system of each alternative treatment. The additional capital and operating expenses required for each treatment are presented on a per system and a per capita basis.

  --costs of a monitoring requirement for systems not affected by the maximum contaminant level.

- The Sensitivity Analyses were conducted for purposes of comparison with the costs above. The elements which are described include:

  --alternative distribution of treatment selection;

  --alternative maximum contaminant levels;

  --alternative system sizes included in regulatory coverage.

In addition to these elements, there is a discussion of the availability of the materials and equipment required for adding the necessary treatments.

Finally, this document includes four appendices which cover, in some detail: the methodology for arriving at national cost estimates; a description of the water quality data used in the analysis; a description of the detailed components of the

individual water system costs for each treatment; and a review of the method for determining the number of systems likely to select each treatment alternative.

Analytic Structure

This section identifies the basic information which was required and the manner in which it was used to develop the costs of the regulation.

REGULATORY CRITERIA

Naturally-occurring organics have become a regulatory concern primarily because of the evidence that chlorine combines with precursor organic matter in water to form chloroform, and other related compounds, which are suspected carcinogens. The regulation to reduce the level of these contaminants in drinking water contains the following parameters:

- A maximum contaminant level (MCL) for trihalomethanes (THM) of 0.10 milligrams per liter;
- A lower boundary for the size of water systems to be covered by the regulation which has been set at 75,000 persons served. In addition, systems serving between 10,000 and 75,000 will be required to monitor for THM.

An MCL of THM at 0.10 milligrams per liter is the level which the Office of Water Supply has selected for the proposed regulatory action. This level allows some flexibility in the type of treatment which can be used as a remedy. It does not, therefore, necessarily force systems to add any particular treatment.

The lower boundary for systems covered by the regulation (75,000 people) is the point at which over 80 percent of the population served by community water systems is covered. The number of systems of that size and larger is relatively small, 390 compared to 3,685 for all systems serving populations of over 10,000, and nearly 55,000 community water systems in total.

In addition to the extent of the coverage offered by the proposed regulation, there are additional reasons for limiting the size of the systems included. The majority of the water systems in the regulated category use surface water which is more likely to have organic contamination. As the size of systems decreases, the water used is more likely to be drawn from a ground water source which, in turn, is less likely to produce trihalomethane concentration at or above the MCL. Further, it is more likely among larger systems that skilled scientists and operators will be available to develop and manage modified treatment practices which assure no reduction of the waters' microbiological quality. Nevertheless, as water quality problems and the feasibility of implementing appropriate treatments among small systems becomes more certain, the regulation may be extended to cover smaller systems.[1]

NUMBER OF COMMUNITY WATER SYSTEMS

This analysis addresses primarily the costs which large systems will incur as a result of the regulation. It is, therefore, important to illustrate how large a portion of the population is served by these large systems. At the same time, it should be noted that 93 percent of the community

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[1] *The first step will be to require monitoring for THM among systems serving between 10,000 and 75,000 people. A discussion on page 18 covers the cost of this monitoring responsibility.*

water systems in operation serve under 16 percent of the population. Figure 1 on the following page illustrates the percentage of water systems in each size category and the related portion of the population which they serve.[8] The numbers of systems in those categories under 75,000 are referred to in a later section (Sensitivity Analysis) which summarizes the costs which would result under different regulatory configurations.

The systems serving over 75,000 have been subdivided into three size groupings: 75,000-100,000; 100,000-1 million; and over 1 million. These size categories permit the cost analysis to reflect such differences among systems as the economies of scale associated with the sizing of equipment for new treatments.

Having established that over 80 percent of the population is served by the 380 systems covered by the regulation, the following discussion summarizes the treatments which are expected to be adopted by those large systems which exceed the MCL.

AVAILABLE TREATMENT ALTERNATIVES

There are three general categories of treatment possibilities. The selection of the appropriate category for a specific water system depends in part upon the magnitude of the system's THM level and the system's existing treatment facility. Systems, of course, will tend to select the alternative which is least disruptive to their current practices and still complies with the regulation.

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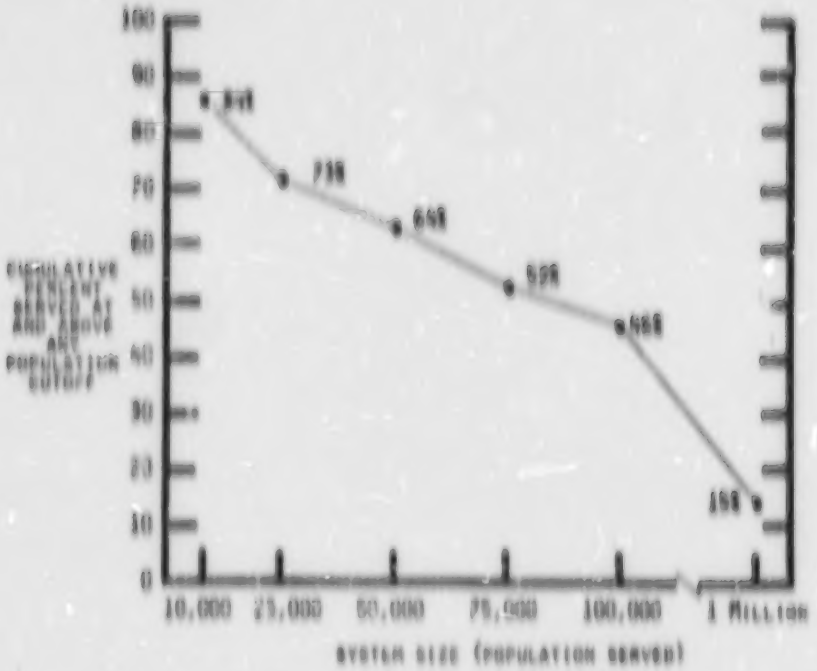
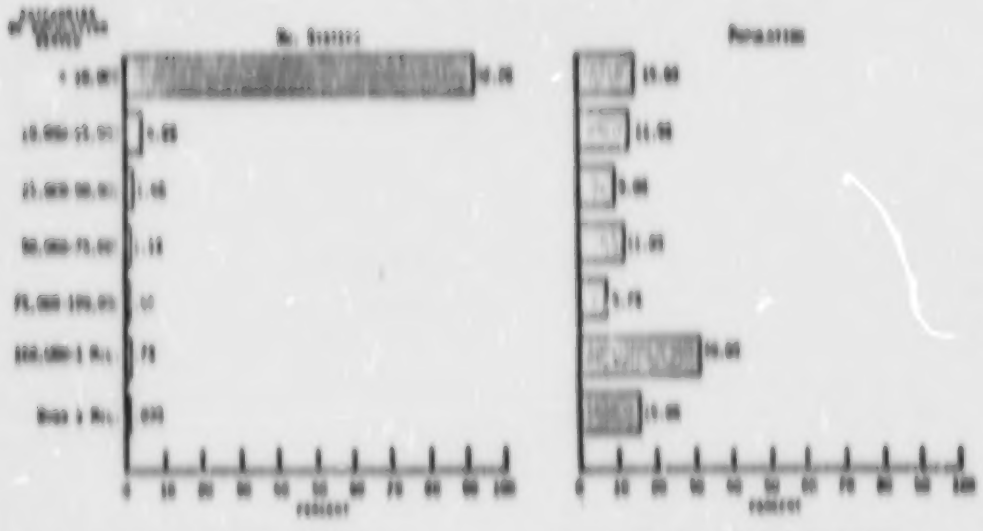
[8] *The size categories have been selected to represent the most logical breakpoints in operating characteristics for systems serving over 10,000 people.*

Figure 1

CUMULATIVE PERCENT OF POPULATION SERVED
BY COMMUNITY WATER SYSTEMS





The major treatment options which are available to meet a THM regulation are described below:

- The first alternative consists of minor modifications to current procedures. These modifications include moving the point of disinfection, adjusting the chlorine dosage, or improving existing conventional coagulation and sedimentation practices. This approach would enable systems where the MCL is exceeded by a small amount to comply at minimal cost.

- Changing disinfectants is the second category of treatments. Since it is the use of chlorine which causes part of the organic problems, some systems may choose to use other chemicals for disinfection. The available alternatives are: chloramines, ozone, and chlorine dioxide.

- Using a tertiary adsorbent is the most complex and costly alternative. Systems with the most serious organic contamination may select treatment techniques which require the use of granular activated carbon (GAC), resins, or an equivalent. This analysis has used the costs of installing GAC in contactors following conventional filtration as those which represent the most likely treatment technique in this category.[1]

PROFILE OF SYSTEMS' RESPONSE TO MCL REGULATIONS

In order to complete the basis for estimating the total costs of the regulation, the number of systems which will select each of the treatments above must be established. These estimates were arrived at by first estimating the number of systems which will exceed the MCL and then allocating these systems according to the treatments they are most likely to select.

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[1] *Another approach available for systems with existing filtration is the replacement of the filter media with GAC. Appendix C, Treatment Costs, provides descriptive detail and cost data for each of the treatment alternatives including filter media replacement.*

Of the 500 community water systems serving populations of 75,000 or more, about 80 have been estimated to exceed an MCL of THM at 0.10 milligrams per liter, based upon the water quality data currently available.[4]

The number of systems which will select each of the treatments available has been estimated on the basis of the THM level, current treatment practices, and the economics of the treatment options. The distribution by treatment category presumes that 45 percent of the affected systems as likely to change disinfectants and 30 percent likely to use an adsorbent. The remaining 25 percent would modify existing disinfection or other procedures. As the table also shows, approximately 84 million people are served by the systems which would be likely to exceed the standard prior to any corrective measures.[5]

MOST PROBABLE TREATMENT SELECTION BY WATER SYSTEMS AFFECTED BY MCL REGULATION OF THM AT 0.10 MILLIGRAMS/LITER

	Move Point of Disinfectant or Adjust Dosage	Change Disinfectant	Use Adsorbent	Total
Number of Systems	21	39	24	84
Percent of Total Affected	25%	46%	29%	100%
Population Affected	9,240,000	14,470,000	7,160,000	83,890,000

[4] *See Appendix B, "Water Quality Data."*

[5] *Appendix D, "Regulatory Compliance Strategies" described the approach used in estimating the number of systems to use each treatment.*

Cost Of The Regulation

The cost analysis of a THM regulation combines the assumptions above on the number of systems likely to be affected by the regulation, and the treatments which those systems will tend to select. In addition, the cost analysis uses the individual water system treatment costs which are described in detail in Appendix C. The results are presented first in terms of the national costs for all large systems requiring treatment and, second, in terms of the costs to individual systems.

NATIONAL COST ESTIMATES

The economic implications of a THM regulation at 0.10 milligrams per liter, covering systems of 75,000 people or more, are summarized below in terms of five key measures:

- Capital expenditures requirements during the 1978-1981 period are projected to be $154.4 million (1978 dollars).
- External financing requirements during the same period for those capital expenditures are projected to be $145.2 million under the regulation.
- Annual operating and maintenance (O&M) expenses in 1981 for the required treatments are estimated at approximately $56.9 million.
- Annual revenue requirements in 1981, reflecting the amortization of capital expenditures and the O&M expenses, is expected to increase by a total of $36.0 million for the 65 systems which are likely to have cost impacts.
- Per capita costs, simply in terms of total revenue impacts divided by the population served by systems with cost impacts, are projected to be $2.07 per year in 1981.

As the table shows, over 87 percent of the aggregate costs of this regulation is expected to be borne by systems serving 100,000 people or more.

SUMMARY OF TOTAL COSTS
FOR AN MCL REGULATION
OF THM AT 0.10 MILLIGRAMS/LITER
(millions of 1976 dollars)

	Systems serving Populations of: 75,000 to 99,000	100,000 and above	Total
Capital Expenditures, 1976-1981	$50.5	$103.9	$154.4
External Financing, 1976-1981	19.0	105.9	146.9
Operating & Maintenance Expenses, 1981	5.0	33.3	38.9
Revenue Requirements, 1981	6.0	32.0	38.0
Annual Per Capita Cost[1], 1981 (dollars)	0.30	0.04	0.07

[1] Revenue requirements divided by population served by cost-impacted systems.

These cost figures include the expenses of all 86 systems adding or altering treatment practices. The following table breaks down these costs into those attributable to each treatment category. About 89 percent of the capital costs are due to the 26 systems which are anticipated to add adsorbents, though these systems are only 30 percent of the number affected by the regulation.

SUMMARY OF COSTS BY TREATMENT CATEGORY
FOR AN MCL REGULATION OF THM
AT 0.10 MILLIGRAMS/LITER
(millions of 1976 dollars)

	# Systems	Capital Expenditures	Annual Revenue Requirements
Change Disinfectant	39	$ 17.3	$ 7.6
Use Adsorbent	26	137.1	29.2
Move Point of Disinfectant	21	.0	0.0
TOTAL	86	$154.4	$36.8

A more detailed summary of the treatment costs for a typical system in the three size categories serving over 75,000 people appears below.

COSTS TO A TYPICAL SYSTEM

The costs for the four types of treatments--ozonation, chlorine dioxide, chlorination/ammoniation and tertiary adsorbent can best be compared on the basis of additional per capita costs for a typical water system. They are as follows:

- Ozonation (plus residual disinfectant) is the most capital intensive of the three disinfectant treatments. Systems serving over 1 million people would need capital expenditures of about $60 million each. Annual per capita costs range from 30 to 85 cents.

- Chlorine dioxide treatment requires only minor investment but considerable expense for the purchase of sodium chlorite. Per capita costs range from 68 to 81 cents per year.

- Chlorination/ammoniation is the least expensive treatment with annual per capita costs in the 38 to 47 cent range.

- Adding a tertiary adsorbent is the most expensive treatment and involves substantial capital expenditures (approximately $10 million for a typical system serving over 1 million people) as well as continuing operating expenses for reactivation. Per capita costs range from $3.30 to $6.11.

The capital expenditures, annual revenue requirements, and per capita costs are shown in the following table for each treatment for each of the three size categories over 75,000.

COMPLIANCE COSTS FOR A TYPICAL WATER SYSTEM UNDER AN MCL REGULATION OF TTHM AT 0.10 MILLIGRAMS/LITER
(1978 dollars)

	25,000-100,000	100,000-1 Million	Over 1 Million
Average Population Served Per System	65,000	186,000	1,000,000
Ozone			
Capital Expenditures	$ 700,000	$1,070,000	$ 5,900,000
Revenue Requirements/Year	70,440	107,331	603,304
Annual Per Capita Cost	.93	.69	.99
Chlorine Dioxide			
Capital Expenditures	$ 30,300	$ 90,000	$ 97,000
Revenue Requirements/Year	60,300	153,500	1,000,000
Annual Per Capita Cost	.61	.81	.68
Chlorination/Ammoniation			
Capital Expenditures	$ 30,000	$ 40,000	$ 70,000
Revenue Requirements/Year	40,300	74,000	430,600
Annual Per Capita Cost	.47	.40	.28
Tertiary Adsorbent			
Capital Expenditures	$2,500,000	$4,300,000	$10,500,000
Revenue Requirements/Year	510,000	808,000	4,671,000
Annual Per Capita Cost	6.11	4.30	3.00

It is clear that the range of costs is broad across treatments and size categories. The use of a tertiary adsorbent is considerably more expensive than any of the alternate disinfectants for all size categories.[6] Among the disinfectants, chlorine plus ammonia is always the least expensive. In the case of ozone compared to chlorine dioxide, there are distinct economies of scale for the use of ozone. This implies that most systems serving over 1 million people would select ozone over

[6] *However, the use of a tertiary adsorbent has the ancillary benefit of generally reducing organic chemicals in addition to TTHM. Its use may also result in reduced disinfectant demand.*

chlorine dioxide on the basis of cost alone. As can be seen in the table, the economies of scale for chlorine dioxide are less because the operating costs increase more directly with production than is the case for ozonation.

The number of systems selecting each of the treatments will have a significant impact on the total costs of the proposed amendment. This is clearly illustrated by the differences in the costs to individual systems of each of the treatments. The next section, therefore, includes an alternative distribution of treatment selection as one of the three sensitivity analyses included for comparison.

MONITORING COSTS

In addition to the treatment costs which the 68 water systems serving over 75,000 will incur, there are specific monitoring requirements included in the regulation. The costs for monitoring which would be incurred by systems exceeding the MCL and adding treatments have already been included in the cost estimates presented above. In addition, two other categories of water systems will be required to conduct monitoring for THM.

First, all those systems serving over 75,000 people which are not expected to alter their current treatment practices will be required to continue monitoring at a minimum frequency of five samples per quarter.

Second, all water systems serving between 10,000 and 75,000 people will be required to monitor for THM at a minimum frequency of two samples per quarter.

The annual national monitoring costs for the 807 systems serving over 75,000 which will probably not need to alter current treatment practices amounts to about $185,800.[7] This estimate is based on a $25 per sample cost, assuming the five sample per quarter minimum, or $500 a year per system. The annual monitoring costs for the second category, the approximately 2300 systems serving between 10,000 and 75,000 are estimated at $460,000. This estimate is based upon two samples per quarter at $25 each, or $200 a year per system.

Monitoring costs were computed based upon a survey of contract analytical laboratories currently performing THM analyses.[8] Per sample costs ranged from $25 to $100. After these regulations have been promulgated, the increased volume of business and competitive factors would be expected to reduce the analytical costs to well below $25 per sample.

EPA expects that a number of community water systems will choose to purchase the equipment and monitor for THM on-site more frequently than the minimum, for operational control as well as for compliance purposes. An additional benefit from purchase and on-site analytical capability, is that the gas chromatograph is versatile and can be used to monitor for the presence of many other organic chemical contaminants besides THM's.

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[7] *These 807 systems are those which remain after subtracting from 880: (1) the 65 systems included in the treatment cost analysis which already will be monitoring and (2) the 18 systems which do not chlorinate.*

[8] *The cost of equipping an existing laboratory with an appropriate gas chromatograph is dependent upon which analytical procedure is selected and the type of instrument. The basic instrumentation for the "liquid-liquid" extraction method consists of a gas chromatograph with an "Electron Capture" detector and recorder; the base cost is approximately $6,000. The basic instrumentation for the "purge and trap" method consists of a gas chromatograph, a "Hall" detector, purge and trap sample concentrator, and recorder; the basic cost is approximately $10,000. In either case, some additional expenditures for accessories would be added.*

Sensitivity Analysis On Alternative Scenarios

There are several variables in the economic analysis which, if changed, produce significant differences in the results. The following section summarizes the effect of:

- Varying the mix of treatments which systems would be expected to select;
- Changing the MCL to a higher or lower THM level;
- Including system size boundaries above and below 75,000 people in the regulation.

ALTERNATIVE DISTRIBUTION OF TREATMENT SELECTION

The economic impacts covered above have assumed a specific set of choices for systems affected by the regulations. If the same systems were to choose a different mix of treatments, the level of total costs would change. Since the behavior of systems is uncertain, an example of the costs for a different mix has been presented below, along with the costs of the most likely mix of treatments.

The major factor determining the total economic impact of a change in treatment mix is the percentage of systems which would use adsorbents instead of changing disinfectants. In the example below, the number of systems using adsorbents has been increased from 30 percent of the systems affected to 50 percent. The projected economic impacts of the regulation change accordingly: annual revenue requirements increase from $36 million to $51 million, a 42 percent increase. Capital expenditures display a similar sensitivity to the assumed mix of complying treatment strategies; they increase by 64 percent or $99 million.

SENSITIVITY OF COSTS TO MIX OF COMPLYING TREATMENTS FOR AN MCL OF THM AT 0.10 MILLIGRAMS/LITER
(millions of 1976 dollars)

	Best Estimate	Higher Use of Absorbent
Percent of Affected[a] Systems Using Absorbent	80%	95%
Capital Expenditures, 1976-1981	$154.4	$253.5
External Financing, 1976-1981	$146.9	$238.3
Operating & Maintenance Expenses, 1981	$ 85.9	$ 94.0
Revenue Requirements, 1981	$ 96.9	$ 91.1
Annual Per Capita Cost,[b] 1981 (dollars)	$ 2.09	$ 3.06

[a] All systems affected by the regulation, including those which can comply through relatively inexpensive modifications in their disinfection procedures.

[b] Revenue requirements divided by population served by cost-impacted systems.

ALTERNATIVE MCLs

The maximum contaminant level of THM at 0.10 milligrams per liter was selected on the basis of the protection it would afford by a considerable reduction of THM in water consumed by a large proportion of the population. This protection could be achieved while minimizing the negative effect on the microbiological quality of the water. Two alternative MCLs were examined in order to illustrate the sensitivity of total costs to a change in MCL. One case represents a somewhat more stringent MCL: THM at 0.05 milligrams per liter; the second represents a less stringent one of THM at 0.15 milligrams per liter. In addition, a test was made on the cost of imposing a very strict regulation, THM at 0.01 milligrams per liter. These results are covered at the end of the section.

Given a mix of treatment selections, the most important variable in determining the economic impact of these alternative MCLs is the number of systems affected. In the first case (THM at 0.05 milligrams per liter), 80 percent--or 141 systems--of the systems serving over 75,000 people would be affected. In the second case (0.15 milligrams per liter), only 9 percent--or 36 systems--would be affected.

The treatment options and mix are assumed to be the same as in the base case. However, the costs for using GAC are somewhat higher in the more stringent MCL because reactivation cycles would be approximately 45 days instead of 60 days; they are slightly lower at 0.15 milligrams because of the need for less frequent reactivation (75 days).[8]

The table below compares the total costs of these alternatives to the cost for THM at 0.10 milligrams per liter. The impact in terms of capital expenditures in the 1978-1981 period is projected to be $934.6 million for the 0.05 milligram level and $103.4 million for the 0.15 milligram level versus the projections presented earlier of $154.4 million for a 0.10 milligram regulation. The other aggregate impacts, such as operating and maintenance expenses and annual revenue requirements, vary similarly.

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[8] *These estimates of the reactivation frequencies required are conservative approximations based upon limited laboratory data. Actual reactivation frequencies will need to be determined by each system and will depend upon the specific water quality of each source.*

SUMMARY OF TOTAL COSTS UNDER ALTERNATIVE MCLs FOR THM
(millions of 1976 dollars)

	Milligrams/Liter		
	0.05	0.10	0.15
Number of Cost-Impacted Systems*	141	80	56
Capital Expenditures, 1976-1981	$ 294.6	$ 154.4	$ 103.4
External Financing, 1976-1981	$ 200	$ 146.8	$ 97.8
Operating & Maintenance Expenses, 1981	$ 49.6	$ 25.9	$ 15.6
Revenue Requirements, 1981	$ 65.1	$ 36	$ 23.1

* Estimated number of systems serving over 75,000 which would be out of compliance and which could not comply through relatively inexpensive modifications in their current chlorination procedures.

The table above summarizes the total costs for all treatments to systems serving over 75,000 which would be incurred under alternative MCLs. However, a system's ability to achieve compliance with a given treatment option will vary depending upon the stringency of the MCL and the condition of the water vis-á-vis the MCL. Therefore, the treatment selection will vary somewhat depending on the MCL.

The following table summarizes the number of systems estimated to select each treatment alternative under three MCLs: 0.05, 0.10, 0.15. In the 0.05 mg/l case, the largest

portion (64 percent) of the 184 systems is anticipated to select to change disinfectants. At this level many of the systems which will exceed the MCL will not have contamination problems severe enough to require the use of GAC. As mentioned previously, this is not the case at the less stringent MCL of 0.15 mg/l. The 0.15 mg/l level is sufficiently high that 40 percent of those which exceed it are assumed to use GAC. On the other hand, the portion of affected systems which will be able to comply with a given MCL by modifying existing procedures increases as the standard becomes less stringent: from 14 percent at 0.05 mg/l to 31 percent at 0.15 mg/l.

SUMMARY OF TREATMENT SELECTION AND CAPITAL EXPENDITURES FOR SYSTEMS AFFECTED AT ALTERNATIVE MCLS FOR THM

Treatment Selected	.....THM @ .05 mg/l..... # Systems	Capital Expenditures	.....THM @ .10 mg/l..... # Systems	Capital Expenditures	.....THM @ .15 mg/l..... # Systems	Capital Expenditures
Change Disinfectant	106	$ 41.0	39	$ 17.3	18	$ 6.4
Use Absorbent	66	103.6	36	137.1	21	96.9
Modify Procedures	23	0	21	0	15	0
TOTAL	184	$144.5	96	$154.4	52	$103.4

The final alternative considered was a very stringent MCL of THM at 0.01 milligrams per liter. In developing costs for this alternative, it was assumed that all systems would use an adsorbent to achieve compliance. With this MCL, 282 systems or 85 percent of the 330 systems serving over 75,000

people would have THM levels in excess of 0.01 milligrams.[10] The systems are assumed to reactivate the adsorbent, on average, with a 45-day cycle. Based on these assumptions, the 283 systems adding adsorbents would spend a total of $1.5 million in capital expenditures alone by 1981.

ALTERNATIVE SYSTEM SIZES INCLUDED IN REGULATORY COVERAGE (THM AT 0.05, 0.10, AND 0.15 MILLIGRAMS PER LITER)

The final example of cost sensitivity is the analysis of extending the coverage of a THM regulation to systems smaller than those serving 75,000 people. This section presents a summary of the number of systems affected and the related costs for:

- Five alternative system size boundaries included in regulatory coverage: (1) all community water systems; (2) those serving over 10,000 people; (3) those serving over 50,000; (4) over 75,000 (the case presented earlier); (5) those over 100,000.
- Three alternative MCLs: 0.05 mg/l; 0.10 mg/l (the base case); 0.15 mg/l.

The first table below covers the proposed MCL of THM at 0.10 milligrams per liter as it would affect the five alternative size limitations. The number of systems which would experience cost impacts would increase substantially as the population cut-off for the regulation is lowered. If the lower boundary were reduced to 10,000 people, then almost six times

[10] *The total number of large systems serving over 75,000 people (580) has been reduced by the 60 systems which purchase the majority of their water. Of the remaining 520 systems, 283 would add treatment under the most stringent regulation (0.01 mg/l). The 283 systems include 184 or 88.8 percent of the surface water systems which chlorinate and 99 or 19 percent of the ground water systems which chlorinate.*

(369) as many systems would have to add new treatments. With no cut-off at all (i.e., a regulation affecting systems as small as 25 people served), the number of systems with cost impacts would rise to 5,121 or about 11 percent of all community water systems in the country.

The aggregated economic impacts would increase substantially if the boundary were lowered to 10,000; however, the addition of the 3,759 small systems below 100,000 would not affect the total cost appreciably. In the case of those systems serving under 10,000 persons, the severity of the impact is at the individual system level, rather than at the national level. Capital expenditures in the 1978 to 1981 period, for example, would increase from $154.4 million with a 75,000 population cut-off to $310.0 million with a cut-off at 10,000, and to $391.0 million with no cut-off at all. Annual revenue requirements in 1981 would increase similarly from $36.0 million with a 75,000 cut-off to $70.5 million at 10,000 people and $95.4 million with no cut-off.

COSTS OF ALTERNATIVE SIZE LIMITATIONS
FOR AN MCL OF THM AT 0.10 MILLIGRAMS/LITER
(millions of 1976 dollars)

	Population Served				
	Serving >25	Serving >10,000	Serving >50,000	Serving >75,000	Serving >100,000
Number of Cost-Impacted Systems[a]	5,121	369	113	65	46
Capital Expenditures, 1978-1981	$391.0	310.0	210.4	154.4	133.0
External Financing, 1978-1981	$366.4	290.9	206.0	145.2	126.9
Operating & Maintenance Expenses, 1981	$ 67.0	49.9	31.1	26.9	23.9
Revenue Requirements	$ 95.4	70.5	45.5	36.0	32.0

[a] Estimated number of systems which would be out of compliance and would select treatments other than the relatively inexpensive modification of disinfection procedures.

The same general patterns can be seen for the other two MCLs as the universes of systems covered becomes larger. In each case there is a dramatic increase in the number of systems which would be affected once the boundary is set to include systems of all sizes. However, the largest proportion of the total cost is borne by the systems serving over 10,000 people. At this point and below the impact on a per capita or a per system basis is more significant than the total costs incurred by these smaller systems collectively.[10]

The two tables which appear below summarize the effect of the alternative MCL's on the five size boundaries.

COSTS OF ALTERNATIVE SIZE LIMITATIONS FOR AN MCL REGULATION OF THM AT 0.05 MILLIGRAMS/LITER
(millions of 1976 dollars)

	Population Served				
	Serving >25	Serving >10,000	Serving >50,000	Serving >75,000	Serving >100,000
Number of Cost-Impacted Systems*	4,822	791	244	141	99
Capital Expenditures, 1978-1981	$ 575.9	468.9	326.4	234.8	204.1
External Financing, 1978-1981	$ 541.3	440.8	306.8	220.9	191.9
Operating & Maintenance Expenses, 1981	$ 117.0	89.5	59.4	48.8	44.7
Revenue Requirements	$ 155.0	120.9	81.0	65.1	58.0

*Estimated number of systems which would be out of compliance and would select treatments other than the relatively inexpensive modification of disinfection procedures.

COSTS OF ALTERNATIVE SIZE LIMITATIONS FOR AN MCL REGULATION OF TTHM AT 0.10 MILLIGRAMS/LITER
(millions of 1976 dollars)

	Population Served				
	Serving >25	Serving >10,000	Serving >50,000	Serving >75,000	Serving >100,000
Number of Cost-Impacted Systems*	1,934	916	65	26	25
Capital Expenditures, 1978-1981	$ 970.9	910.8	146.7	103.4	90
External Financing, 1978-1981	$ 294.0	200.0	137.9	97.2	84.6
Operating & Maintenance Expenses, 1981	$ 40.9	30.5	18.7	15.6	14.0
Revenue Requirements	$ 58.7	44.6	28.3	22.3	19.8

*Estimated number of systems which would be out of compliance and would select treatments other than the relatively inexpensive modification of disinfection procedures.

An important economic indicator has been omitted from these tables, annual per capita costs. These costs provide a method for comparing cost impacts among systems of different sizes as well as between different treatments. In order to avoid the inaccuracies of averaging costs to both small and large systems, the per capita costs have been calculated for seven size categories of water systems in terms of populations served: 25-1,000; 1,000-5,000; 5,000-10,000; 10,000-75,000; 75,000-100,000; 100,000-1 million; and over 1 million.

The per capita costs are shown below for each of the four treatment alternatives. The costs for each treatment are the same for each of the three MCL's covered above, except for GAC where different reactivation cycles affect costs. It should be noted that the per capita costs shown represent average system sizes, mix of customers, and production levels and will vary from system to system depending on local conditions. The costs shown represent the total direct and indirect costs which would be borne by residential customers and are not simply the estimated increases in water rates.

The costs shown below are for systems whose size is the arithmetic average of a random sample of community water systems in each category. These sizes differ from the typical systems which were discussed earlier on pages 11 to 13. The differences between average and typical systems are discussed in Appendix A, page A-13.

APPROXIMATE PER CAPITA COSTS IN 1981
BY SYSTEM SIZE CATEGORY AND TREATMENT
(1976 dollars)

Treatment	Population Served						
	25-1,000	1,001-4,900	5,000-9,900	10,000-24,900	25,000-99,000	100,000-1 Mil	1+ Mil
Granular Activated Carbon	$ 2.30	1.60	1.10	.80	.70	.50	.50
Chlorine Dioxide	$ 4.60*	.70	.70	.70	.70	.70	.70
Chlorine Amonia	$ .70	.60	.60	.60	.60	.60	.60
Tertiary Air Stripping*	$11.40	11.40	11.40	8.10	8.00	8.10	8.00

*Cost of this unit partially based upon the use of acidic fluoride, a technique which is considered better suited to the drinking characteristics of systems serving fewer than 500 people.

*Assumes use of upon electricity regeneration cycle.

Summary of Demand on Supplying Industries

Aside from the costs of adding treatments to comply with the organics regulations, EPA has also considered the level of demand which would be placed upon industries supplying the required materials and equipment. The five areas examined include:

- Granular activated carbon
- Regeneration furnaces

- Chlorine dioxide
- Ozonators
- Ammonia

In general, the conclusion is that under the proposed regulation, given the most likely distribution of systems using each treatment, no significant problems exist at the present time for satisfying the demand in any of the areas listed above. With the exception of chlorine dioxide, an industry in which rapid expansion is possible, the estimated demands are well within the capacity of the industries providing the material

It should be noted, however, that these demand projections are based upon the needs of those systems assumed to be out of compliance. Demand could be somewhat higher under at least two conditions: (1) systems which do not exceed the MCL nevertheless decide to add a treatment which will reduce their THM levels, and (2) systems which do exceed the MCL add more treatment capacity to reduce THM levels considerably below the MCL. If both conditions occurred, the demand projections would be low.

GRANULAR ACTIVATED CARBON

A THM regulation will result in some systems treating their water with adsorbents. If granular activated carbon (GAC) were used by all such systems, the demand for the initial fill of GAC would be 35 million pounds for systems exceeding THM requirements. Such a requirement for 35 million pounds of GAC, along with the annual replacement of carbon lost in reactivation cycles, could easily be met by the carbon industry, even within a single year. If the regulation of THM covered systems in all size categories (rather than only those serving over 75,000) then those systems likely to choose GAC would cause the demand

for carbon to increase from 35 to 53 million pounds. Since the industry's excess capacity is over 100 million pounds per year, the demand could be met regardless of the number of systems affected.

REGENERATION FURNACES[11]

A THM regulation at 0.10 milligrams per liter would create a demand for at least 26 furnaces for systems treating for naturally-occurring organic contaminants. These numbers should be viewed as minimum requirements since many of the larger systems, particularly those serving over 1 million persons, often have more than one treatment plant. At these larger sizes it is more economical to purchase a furnace at each plant rather than transport large volumes of carbon to a central furnace location. Even if the estimate of 26 furnaces were increased substantially, the furnace industry could supply an adequate number of furnaces.[12] A regulation covering systems below 75,000 persons served could create a much larger demand for furnaces, possibly reaching the furnace industry's current excess capacity of approximately 200 custom-designed furnaces per year.

CHLORINE DIOXIDE

The use of chlorine dioxide treatment rather than chlorination to meet a THM regulation could create an annual increased demand for slightly under 8 million pounds of sodium chlorite. Excess industry capacity of at least 3 to 4 million pounds presently exists. The industry claims rapid capacity expansion is possible if required by additional demand.

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[11] *The terms regeneration and reactivation are used interchangeably in this report.*

[12] *A two-year lead time is generally required for the design, construction and start up of custom regeneration furnaces.*

OZONATORS

A second alternative to chlorination as a disinfection process is ozonation. Such a treatment will require the purchase of an ozonating system to produce the needed ozone with electrical energy. Since approximately eight water systems are expected to use the ozone disinfection process, and since some large systems with more than one treatment plant would purchase several ozonating systems, the number of ozonating systems (2-4 ozonators each) required is likely to be in the range of eight to twelve. Since the demand is relatively sma , no production capacity constraints would affect implementation of the regulation.

AMMONIA

A third alternative method of disinfection is the use of ammonia in combination with chlorine. The use of this treatment to meet the trihalomethane standard could create an annual demand for about 3 million pounds of ammonia. Given the annual production of ammonia, this demand level is minimal and creates no constraint to compliance.

The following table summarizes the estimated demand for the major equipment and materials likely to be needed by water systems affected under the proposed MCL regulation.

[illegible]

[illegible]	[illegible]				[illegible]				[illegible]	
[illegible]	[illegible]									
[illegible]	35	357	35		359	0	5	0	465	2

Note:

1. [illegible]
2. [illegible]
3. [illegible]
4. [illegible]
5. [illegible]

APPENDIX A

Methodology and Modelling

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APPENDIX A

METHODOLOGY AND MODELLING

GENERAL APPROACH

The overall methodology for estimating the economic impact on community water systems of various federal regulations is composed of five principal elements. They are described briefly below.

A Policy-Testing Computer Model. The model, PTm Water Utilities, is the basic computational and forecasting tool used to process and report on the information compiled and analyzed in the other principal elements of the methodology.

Current Fiscal and Operating Practices of the Water Utilities Industry. A survey of 1000 water systems of all sizes, ownerships, and water sources was conducted to supplement existing information on the current structure and characteristics of community water systems. The results were analyzed and prepared as input to the policy-testing model, providing the data for the baseline projections of the industry used in the analysis of regulatory impacts.

Data on Water Quality (Total Trihalomethanes). Surveys of organic contaminants in drinking water have been conducted over the past two years by EPA's Municipal Environmental Research Laboratory (MERL) and the Office of Water Supply, Technical Support Division Laboratory. The information from those surveys, while not completely representative of the industry, has been used to estimate the type and degree of water supply contamination by organics across the country. These estimates were used to determine the proportion of water systems likely to exceed specified maximum contaminant levels and therefore likely to require additional treatments.

Treatment Cost Data. Some of the treatment techniques which water systems may choose to adopt in order to comply with a THM regulation are not widely used in the industry at this time. As a result, detailed estimates of capital and operating costs on a unit basis had to be researched and developed for each of five treatments. These costs were developed for nine size categories of water systems in order to reflect major differences in production levels and operating practices.

Regulatory Compliance Strategies. Systems whose water contamination level exceeds the regulatory guidelines have various alternatives available for achieving compliance. In order to estimate the economic impact of any regulation, it was necessary to determine the specific number and type of systems likely to select each treatment alternative. A decision tree structure was developed to distribute non-complying systems according to the most probable combination of treatments likely to be used for complying with a given regulatory standard.

Each of these principal elements is the result of extensive research and analysis. Each also contains a number of critical assumptions which influence the outcome of the economic impact analysis and should be described in further detail. Consequently, the remainder of this appendix will cover the major components of the water utilities model, present sample baseline data as derived from the survey and discuss the major assumptions embedded in the modelling methodology. Subsequent appendices contain expanded descriptions of the remaining elements: the Water Quality Data (Appendix B), Treatment Cost Data (Appendix C), and Regulatory Compliance Strategies (Appendix D).

Modeling Approach

The Policy-Testing Computer Model draws on the data from the four other elements in the methodology--the current industry practices, water quality data, treatment cost data, and regulatory compliance strategies--to calculate the economic impacts presented in the preceding paper. Simply described, the model determines the number of systems which would select each new treatment as a result of the regulation being examined (using water quality data and regulatory compliance strategies) and then applies the relevant treatment costs. The model determines the financial impact of those additional costs on the utility's overall operating statements for a specific future year. A comparison of these new financial statements with the baseline reports yields an estimate of the economic impact of the regulation.

These computations require a complete recalculation of the financial flows of funds that take place in a water utility during a full year. A major element of these calculations centers on capital items. The model projects capital expenditures financing by a combination of available internal sources and external sources, which include both debt and equity at prevailing rates of return. The revenues required in a given future year by a system requiring a new treatment consist of the baseline revenues (those for normal operations) plus operating and maintenance costs for the new treatment plus the annualized costs (capital costs plus depreciation) of the capital expenditures for the new treatment.

Per capita costs have been calculated in this paper simply by dividing the additional revenues required for a

given treatment (excluding the baseline revenues for normal operations) by the total resident population served. This method of assuming all costs would be passed along to residential customers tends to state per capita costs at the maximum level since a portion of the costs would normally be billed to commercial, industrial, and wholesale customers also served by the utility. However, the increased costs of goods and services produced by non-residential customers will, in many cases, be passed along to the residential population. As a result, the attribution of all treatment costs to residential users approximates the combined direct and indirect costs to residents of new treatment additions.

The Water Utilities

The analytical model of the water utilities industry was developed as a method to test the impact of a wide range of regulatory alternatives under the Safe Drinking Water Act. As such, it is designed to handle large amounts of data and to allow for maximum flexibility in the level of analytical detail and in the presentation of results.

In general, all the modelling operations fall into two broad categories of analysis and results. The first is the forecasting of the basic operating and financial characteristics of the water utility industry for a base year (1978) and into the future (1981, 1985).[1] These forecasts which assume no additional treatment requirements are referred to as baseline reports. These forecasts are made for each of nine size categories of water systems[2] and for both publicly

[1] *This is the current time horizon. The year can be extended as necessary.*

[2] *The nine size categories are based upon the number of year-round residents served by the water systems. The categories are as follows: 25-99, 100-499, 500-999, 1000-2499, 2500-4999, 5000-9999, 10,000-99,9999, 100,000-999,999 > one mil.*

and privately-owned systems. In addition, the forecasts include projections for the industry as a whole, as well as for a representative or typical water system in each size category.

The second general category of modelling operations is the forecasting of the economic impacts of a selected regulatory option. The impact is reported in the same manner as the baseline reports, but the impact of each specific treatment can be isolated in terms of new operating costs, capital expenditures, and revenue requirements needed for that treatment. It can also be examined in terms of its impact on a typical affected system or, in aggregate, on the industry as a whole.

PROGRAM MODULES

In order to maintain the flexibility required for changes in input data and assumptions, there are four independent program modules which operate to produce the forecasts mentioned above.

- The Demand Program which projects population, customers, number of systems, water production, and water sales (gallons).
- The Capacity Program which projects capacity needs and additions as well as capital expenditures for plant and equipment.
- The Treatment Program which projects treatment application rates, operating and maintenance expenses, and capital expenditures for each major regulation specified.
- The Finance Program which projects all the financial variables that comprise the balance sheet, income statement, and sources and uses of funds statement, and which computes consumer charges for residential and other customers.

PRIMARY FEATURES

The water utility industry is relatively large in terms of the number of water systems currently operating (about 55,000) and relatively diverse in terms of the size and complexity of system operations (with systems ranging from those serving 25 people to those serving over 1 million). A primary feature of the water utilities model is its capacity to project and report on data across this broad range. Some of the specific characteristics of PTm's forecasting and reporting of results are listed below:

- Projections are made separately for nine different sizes of water systems (population served) so that the impacts can be identified in each segment of the industry as well as in aggregate.
- Financial data and projections are available separately for public and private ownership classes, since financing needs and solutions may be different for each. In addition, the financial results can be reported in either current or constant dollars, depending upon the needs of the user.
- Three different water sources (ground, surface, and purchased) are analyzed separately when projecting costs of water production and treatment, and these results are aggregated for the financial analyses.
- The analysis of regulatory options includes the consideration of differences among system size categories in terms of the numbers of systems affected and the types and costs of treatments which might be added.

OUTPUT REPORTS AVAILABLE

The Report Writer, a separate component of the model, contains a large number of report formats which enable the user to request the model's projections in the most useful

format for him. Examples consisting of three of the nine reports available are included in the pages that follow.[3] The Summary Report, which presents the major items from the eight other reports, is shown first as Exhibit A-1. This report presents 1976 data on average daily water production, capital expenditures, sources of funds, operating revenues and expenses, and consumer charges for a typical water system in each of the nine size categories. Exhibit A-2, the Income Statement, provides more detail on operating revenues and expenses for these same typical systems in 1976. The Balance Sheet report, included as Exhibit A-3, illustrates specific asset and liability categories.

Key Assumptions

An important aspect of the modelling approach introduced above is the series of basic assumptions currently used in the model's calculations. These assumptions are the result of integrating the survey information, published data, consultations with industry personnel, and professional judgement. Some of the major assumptions are summarized in the sections below.

WATER UTILITY INDUSTRY--ITS SIZE AND SCOPE

The baseline projections for the industry start with a specific number of water systems estimated to exist in each of the nine size categories. These numbers appear on the summary printout in Exhibit A-1 along with the average production per capital per day, and the average number of people served per system.

[3] *All reports are available by selected year, ownership or size category for all systems or typical systems.*

The number of systems has been derived from the EPA Inventory of Water Systems (January 1976) and modified according to experience in the survey. The existence of duplicate systems, systems no longer operating, or systems serving fewer than 25 people in the inventory warranted a reduction in the total number of systems assumed to exist. At the same time, the total of approximately 35,000 systems does not include systems which are federally-owned and operated, systems in Alaska, Hawaii, or territories, or any systems which do not sell some portion of their water directly to retail customers.[4] The result of these exclusions, which were necessitated by lack of representative data for those categories, is that the current cost estimates do not include any costs for a small number of additional systems which may be covered and affected by the proposed regulation.

The average population served by water systems ranges from 56 in the smallest category to 2.4 million in the largest category. Production is the second measure of system size. Average deliveries to residential customers are in the range of 70 to 110 gallons per capita per day for all system sizes. The total production for all customer classes, however, differs greatly among system sizes (e.g., 214 gallons per capita per day for systems serving over 1 million people vs. 98 gallons per capita per day for those serving under 100 people).

BASELINE TREATMENT PRACTICES

The baseline projections, before consideration of regulations under the Safe Drinking Water Act, assume that

[4] *Two systems which are exclusively wholesalers have been identified to date--the Metropolitan Water District of Southern California and the Metropolitan District Commission of Boston.*

the mix of treatments used by water systems in 1976 will remain constant for each cost size category. Additional treatments and the associated costs which may result from the Interim Primary Drinking Water Regulations or the Effluent Guidelines (Water Pollution Control Act) have not been included in the baseline forecasts.

GROWTH IN THE WATER UTILITY INDUSTRY

It has been assumed that the industry will experience modest growth over the next 5 years. The combination of a continued growth in population and the number of customers with a small annual growth rate in the amount of water used per customer is expected to result in increases in water production for the average water system by 1981 of from 0 to 14 percent for various system sizes. In addition, current analysis has not provided the basis for including a quantitative estimate of price elasticity in water demand, although any major change in rate structures in the future may suggest the need for a price elasticity assumption.

CREATION OF NEW WATER SYSTEMS

Growth in the industry will also result from the entry of new systems into the total number of water suppliers. Based upon the number of systems in the survey which began operating between 1970 and 1975, about 2800 new systems are estimated to be added by 1981. Over 75 percent of these (2167) will serve populations of under 500 people. All new systems are expected to serve fewer than 5000 people apiece. The assumption is that new systems will be for small towns providing town water for the first time, new subdivisions, new trailer parks, and other independent developments.

The general characteristics of these new systems are expected to be similar to those of existing systems. That is, new systems will be added with the same mix of ownership, water sources, fiscal and operating practices as exist in 1976.

CONSTRUCTION PRACTICES

Water systems are expected to replace or expand production, treatment, and distribution capacity over time as their systems age and their customer base grows. It has been assumed that systems will build in anticipation of future needs for production and distribution and will do so in five-year cycles. That is, major new additions will be constructed once every five years rather than on an annual basis. The estimated size of new capacity is based upon maximum day production levels to account for the industry's practice of building to accomodate seasonal peak needs and in anticipation of future growth. The maximum production requirements change as the average production requirements increase, based upon the starting ratio of maximum day to average day production.

Based upon general industry practices, new plant and equipment for production and treatment are depreciated in the model over forty years,[8] and distribution system equipment is depreciated over 100 years.

FINANCING

As indicated previously, the financing of capital items has an important effect upon the water industry's ability

[8] *The forty-year period represents the average usable lifetime of this equipment. Some items, such as excavators, may require replacement in less than forty years while the lifetimes of other items may exceed this average.*

to assimilate any major new requirements for capital expenditures. In projecting the financing for capital additions, PTm projects the internal flows of funds and then assumes that any remaining funds needs would be financed in the external capital markets. That financing could take the form of long-term debt, common stock or paid-in capital (for investor-owned systems), or other capital such as budget appropriations or assessments (for publicly-owned systems).

The projections in this analysis were that approximately two-thirds of the funds for normal capital expenditures in the 1976-1981 period will come from internal sources. The model projects, however, that additional capital expenditures to meet a new regulation will have to come almost exclusively from external funds (94 percent) because the internal sources will be nearly exhausted for the other programs.

When external financing is required, the assumption used in this analysis is that it will be obtained in a way which maintains the historic mix of capital sources. That implies that approximately one-third to one-half of the external financing would be in the form of long-term debt and the remainder would be in the form of stock or other capital. Other assumptions on financing include the following:

- Long-Term Debt Interest Rates. The embedded rate for existing debt varies from 4.4 to 6.0 for public systems and from 4.5 to 10.3 for investor-owned systems. The interest rate on new debt is estimated to be 8 percent per year for all publicly-owned systems and 9 percent for investor-owned systems in all size categories.

- Return on Equity. The rate of return on common stock is fairly low in this industry; rates varying from .7 in the smallest size category to 1.5 percent in the largest category have been assumed for investor-owned systems. In addition, the general operating surplus for publicly-owned systems has been expressed in the model as a return on other capital and averages less than 0 percent for most system size categories.

WATER RATES AND CUSTOMER CHARGES

Calculations of water rates in the Policy-testing Computer Model are reported both on a cents per 1000 gallons delivered and an annual cost per capita basis.[6] In both cases, the rates charged cover all operating and maintenance costs, capital charges, and a return on invested capital.

The output reports included as Exhibits A-1 and A-2 show rates per 1000 gallons both as average required rates and as rates for individual rate categories. Average required rates are calculated to equal the level needed to fully cover the utility's costs and expected returns. The rates for individual customer categories are based on the actual rates reported by the 1000 systems surveyed. The weighted average of these rates may not equal the average required rates because in some cases the reporting systems do not fully cover their costs and capital returns with their revenues (in fact, a significant number of the smallest systems do not even charge for water).

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[6] *As discussed on pages A-3 and A-4, per capita rates are simply required revenues divided by population served.*

AVERAGE AND TYPICAL WATER SYSTEMS

Within each of the nine system size categories the Policy-testing Computer Model contains data on water systems with two different sets of characteristics. The first set of data represents average systems which, when multiplied by the numbers of systems in each size category, yields the correct arithmetic totals for each category. The wide range and pattern of data within each of the nine size categories, however, results in averages which do not truly represent what could be called a typical or representative system in each category. The averages are generally higher than the medians for most characteristics, because of the existence of a few systems with very large production volumes and expenses in each size category.

As a result, a second set of data based on median data rather than on means has been included in the model's data base. The data on these typical systems is more valuable for analysing the effect of a regulation upon a representative individual system of a certain size. It does not, however, yield correct national totals when multiplied by the number of systems in each size category.

INDUSTRY STRUCTURE

The overall structure of the industry as reflected in the proportion of publicly-owned and investor-owned systems and of systems using ground, surface, and purchased water sources has been maintained throughout the forecasting period. The current projections do not assume a trend toward regionalization of water systems or any other major changes in industry structure. If such changes are hypothesized and

can be defined for analysis, they could be examined through the use of the Water Utilities model.

PURCHASED WATER SYSTEMS

The modelling methodology used to evaluate potential new regulations affecting community water systems will project costs and the number of systems affected separately for surface, ground, and purchased water systems. In evaluating a trihalomethane regulation, however, it was assumed that the purchased water systems would not be directly affected by this regulation. The evaluation assumes that the system selling water to a purchased water system is providing the primary treatments and would be the system required to make changes in its treatment practices if any are required.

EXHIBIT A-1

1976 SUMMARY REPORT

TYPICAL SYSTEM
(THOUSANDS 1975 DOLLARS)

FINANCIAL MODEL OF COMMUNITY WATER SYSTEMS
TEMPLE, BARKER AND SLOANE

SUMMARY REPORT

	25-99	100-499	500-999	1000-	2500-	5000-	10,000-	50,000-	> 1 MIL.
NO. OF SYSTEMS	6388.0	11714.0	4932.0	4958.0	2484.0	1686.0	340.0	102.0	21.0
AVG. POPULATION (000 ES)	6.8	27.7	63.7	135.1	452.3	897.6	2288.7	10491.4	2029.1
CAPITAL EXPENDITURES (CON.)									
FOR TREATMENT	.0	.0	.0	.0	.0	.0	.0	.0	.0
OTHER	.3	1.4	3.0	15.5	36.9	87.5	177.4	1185.7	7788.0
SOURCES OF FUNDS									
TOTAL SOURCES (CON.)	.3	1.4	5.0	19.3	66.1	77.7	254.4	1645.9	12286.6
EXTERNAL SOURCES (CON.)	.1	.2	2.1	14.3	36.4	65.4	77.7	445.2	4277.9
OPERATING REVENUES AND EXPENSES									
TOTAL OPERATING REVENUES	1.1	6.2	17.2	36.2	85.0	156.4	553.3	4425.2	31085.1
O/W COSTS FOR TREATMENT	.0	.0	.0	.0	.0	.0	.0	.0	.0
CHARGES (CHARGES/COSTS/1000 GALS.)									
RESIDENTIAL	28.9	79.9	113.3	78.1	56.9	53.7	39.1	39.0	38.7
REVENUE- ALL CUSTOMERS	53.9	85.1	86.1	76.1	57.1	53.9	38.9	42.0	39.3
CHARGES (CHARGES/CAPITA/YEAR)									
RESIDENTIAL	8.9	31.7	33.9	28.8	21.2	24.2	27.7	21.6	17.1
REVENUE- ALL CU 198	23.9	35.4	29.8	29.8	26.7	29.1	26.3	28.1	21.2

[illegible] BASELINE TYPICAL

[illegible]

[illegible]
REGION II
[illegible] OWNERSHIP
CONSTANT DOLLARS

TYPICAL SYSTEM DATA
(THOUSANDS OF DOLLARS)

EXHIBIT A-2

1976 INCOME STATEMENT

TYPICAL SYSTEM
(THOUSANDS 1976 DOLLARS)

FINANCIAL MODEL OF COMMUNITY WATER SYSTEMS
[illegible]

PROJECTED INCOME STATEMENT

	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	1.12	4.37	17.72	34.[illegible]	65.80	154.39	553.02	4[illegible]	3[illegible]
-O AND M EXPENSE	.81	4.21	18.73	36.17	59.68	96.76	263.27	2[illegible]	13[illegible]
-[illegible]	.47	.80	.80	.80	.80	.80	.80	.80	.80
-DEPRECIATION EXPENSE	.71	.92	1.36	2.56	6.98	10.29	57.46	477.91	3[illegible]
-LOCAL TAXES	.23	.41	1.34	1.39	3.39	17.32	101.76	574.68	4[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	.11	.48	3.79	6.39	16.19	77.78	139.48	1[illegible]	7[illegible]
-INTEREST EXPENSE	.80	.48	3.10	5.95	15.11	30.71	96.38	661.77	5[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] BEFORE TAXES	.11	.48	.69	.33	.99	7.47	33.01	497.57	3[illegible]
-STATE AND FED INCOME TAXES	.80	.84	.86	.42	.89	.33	4.38	27.87	113.17
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
NET INCOME	.11	.44	.69	.31	.71	7.14	29.02	369.59	2[illegible]
-[illegible] DIVIDENDS	.80	.80	.80	.80	.80	.80	.86	.88	.80
-COMMON DIVIDENDS	.87	.12	.89	.01	.41	.39	4.71	77.87	3[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] EARNINGS	.84	.42	.33	.31	.88	6.74	25.11	3[illegible]	2[illegible]

CONSUMER CHARGES (IN $ PER 1000 GALS)

AVERAGE RATE	.74	.11	.84	.74	.17	.34	.41	.42	.38
RESIDENTIAL	.11	.48	1.11	.78	.79	.54	.54	.59	.58
COMMERCIAL/INDUSTRIAL	.35	.81	.41	.84	.58	.49	.48	.38	.38
WHOLESALE	.23	.38	.87	.48	.45	.88	.88	.33	.33
OTHER	.88	.38	.85	.89	.88	.41	.39	.42	.34

[illegible]

[illegible]
[illegible]
TOTAL OWNERSHIP
CONSTANT DOLLARS
TYPICAL SYSTEM DATA
(THOUSANDS OF DOLLARS)

EXHIBIT A-3

1976 BALANCE SHEET

TYPICAL SYSTEM
(THOUSANDS 1976 DOLLARS)

FINANCIAL MODEL OF COMMUNITY WATER SYSTEMS
TEMPLE-BARKER AND SLOANE

PROJECTED BALANCE SHEET

	25-49	100-499	500-999	1000-	2500-	5000-	10,000-	100,000-	ALL SYS.
ASSETS									
CASH AT ASSETS	2.6	8.0	24.1	57.9	85.8	187.5	329.5	4142.7	33663.0
WATER PLANT—									
PRODUCTION/TREATMENT	4.5	78.1	38.0	66.9	154.1	302.7	1357.0	13884.8	113898.9
DISTRIBUTION	4.6	31.6	84.5	165.7	402.3	842.6	3945.8	36297.9	274826.1
OTHER PLANT AND EQUIPMENT	2.5	15.2	24.2	38.9	107.9	196.9	1032.8	9542.7	45102.4
TOTAL WATER PLANT	11.6	67.9	146.7	294.6	664.3	1332.6	6359.8	59725.4	433827.5
—ACCUMULATED DEPRECIATION	3.5	7.7	26.5	38.2	63.9	215.2	1546.5	13288.5	114347.5
NET PLANT AND EQUIPMENT	8.1	60.3	120.2	256.3	600.3	1117.4	4813.3	46436.9	319480.0
TOTAL ASSETS	10.7	68.3	150.3	314.3	774.1	1304.9	5142.9	46581.1	354103.0
LIABILITIES									
CURRENT LIABILITIES	1.1	22.4	25.4	35.4	36.9	38.3	402.8	3574.6	26870.7
CONSTRUCTION ADVANCES	.0	.0	.0	.0	.0	.0	.0	.0	.0
LONG TERM DEBT	.0	.0	60.7	118.6	279.8	597.1	3639.6	33671.9	277552.7
OTHER CAPITAL ITEMS	.9	25.0	51.5	137.1	398.1	604.5	3627.0	33586.8	318859.6
COMMON STOCK	3.8	19.2	10.9	19.3	43.5	48.2	479.4	4448.7	33960.7
PREFERRED STOCK	.0	.0	.0	.0	.0	.0	.0	.0	.0
RETAINED EARNINGS	1.8	3.7	2.0	3.0	12.5	16.8	141.3	1306.4	9946.2
TOTAL LIABILITIES	10.7	68.3	150.3	314.3	774.1	1304.9	5142.9	46581.1	354103.0

A-14

APPENDIX B

Water Quality Data

APPENDIX B
WATER QUALITY DATA

A major element in calculating the cost of a regulation is the determination of the number of water utilities who will have to add to or alter their treatment practices to comply with the regulatory standard. Data from the first two rounds of the National Organic Monitoring Surveys (NOMS I and NOMS II) have been used in this analysis for determining the number of affected systems. These surveys were conducted by EPA's Office of Water Supply, Technical Support and Division Laboratory and the Municipal Environmental Research Laboratory. The results yielded data on a broad range of known and suspected organic contaminants in drinking water, including trihalomethanes.

NOMS I was conducted during the winter months of early 1976 and included samples from approximately 113 water systems; 93 percent of these systems serve populations greater than 50,000. These samples were shipped to the laboratory under iced conditions to retard the continued formation of trihalomethanes from the precursor organic compounds. During this phase of the survey; the data yielded the following results: the mean level of THM was .066 milligrams per liter, the median was .045 and the range was from zero to 0.457 milligrams per liter.

NOMS II, conducted during the summer months of 1976, covered many of the same water systems and indicated that the levels of trihalomethane compounds were significantly higher than in the previous sample. In this instance, THM production was allowed to reach the maximum level. This was accomplished by not dechlorinating the water samples and maintaining an ambient temperature for several days prior to analysis. The

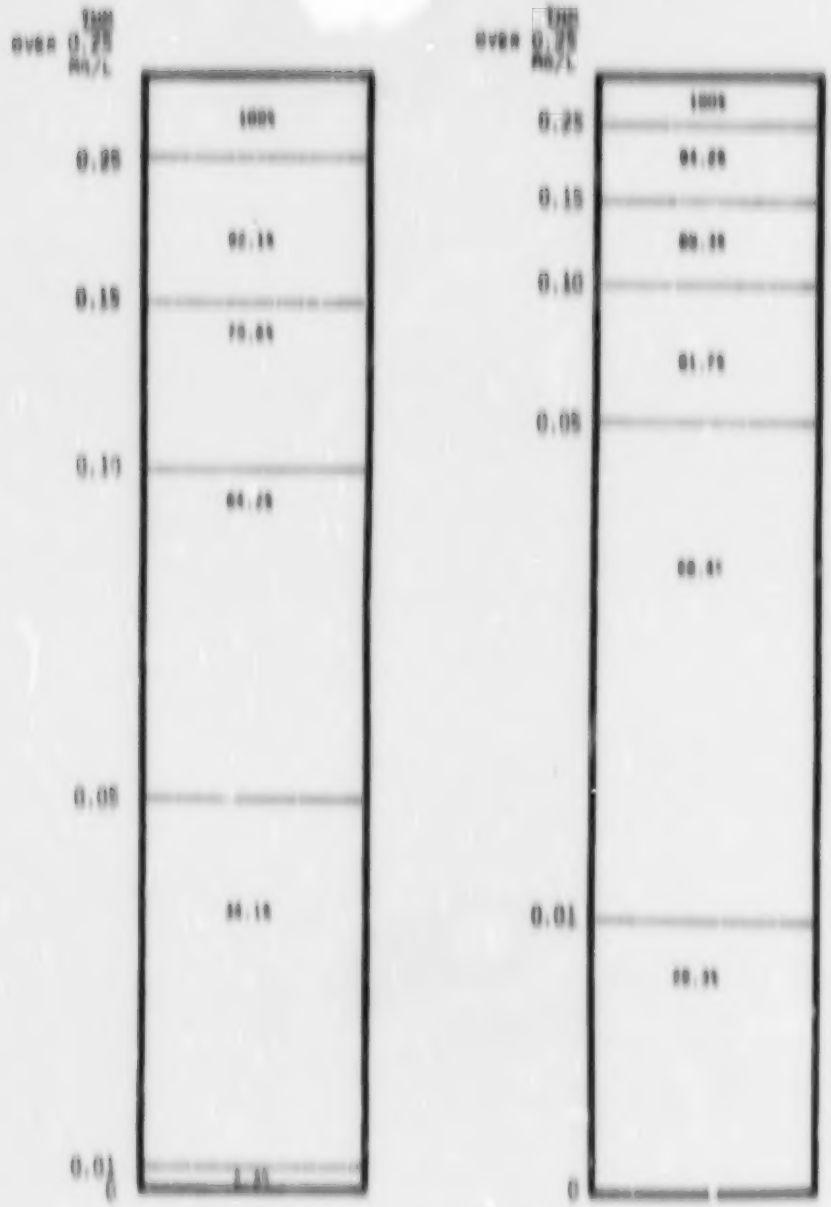
difference was attributed to a normal seasonal fluctuation in trihalomethane precursors, higher seasonal temperatures, and shipments to the laboratory without iced conditions.

During the second phase the data resulted in a mean THM level of .117 milligrams per liter, a median of .087 and a range of zero to 0.784 milligrams per liter.

The data for NOMS I and NOMS II at each site were averaged for use in this analysis. The combination provides a proxy for the annual average data likely to be found by water systems complying with the monitoring requirements of a regulation. The first exhibit shows this combined data in detail. For example, on that basis, 84.2 percent of the surface water systems and 81.7 percent of the ground water systems showed THM levels of less than 0.10 milligrams per liter.

The combined data were analyzed to estimate the number of systems exceeding certain levels of THM contamination. The second exhibit in this appendix displays the number of systems in several system size categories which are estimated to exceed the THM level of 0.10 milligrams per liter. A total of 4,577 systems are estimated to exceed this level, but 4,085 of these are small systems, each serving fewer than 10,000 people. Of the 492 larger systems also exceeding this level, 406 are in the 10,000-75,000 size category and 86 serve more than 75,000 people.

Exhibit B-1
THM CONCENTRATION IN MILLIGRAMS/LITER
BASED ON COMBINED NOMS I AND NOMS II DATA
(PERCENTAGE FIGURES ARE CUMULATIVE)



NOTE: PERCENT SHOWS PORTION OF WATER SYSTEMS WITH THM LEVELS AT OR BELOW NUMBER INDICATED TO THE LEFT OF THE BAR.

[redacted]

[redacted]

System Size by Population Served	All Systems				Systems Which Chlorinate			Systems Which Chlorinate and Have TOX Levels > 0.10 Milligrams per Liter		
	S	G	P[2]	Total	S	G	Total	S	G	Total
Over 1 million	10	1	0	11	10	1	11	4	0	4
100,000–1 million	155	60	21	232	139	64	204	45	11	56
75,000–100,000	40	70	29	147	40	67	107	10	10	20
10,000–75,000	770	1,565	447	2,385	723	948	1,671	250	258	508
Under 10,000	4,709	28,550	4,697	34,756	4,446	33,555	37,770	1,565	2,559	4,585
TOTAL	5,697	30,430	5,394	37,431	5,343	34,435	39,749	1,873	2,737	4,577

[1] Figures include anticipated treatment changes due to the Interim Primary Drinking Water Regulations and growth in the number of systems which serve fewer than 10,000 people.

[2] Water will ordinarily be assumed to have been treated by the seller. Those systems which purchase the majority of their water would not require additional treatment. P = more than 50 percent of the water distributed by the system is purchased. Similarly, S = 100 percent surface water, and G = 100 percent ground water.

APPENDIX C

Treatment Costs

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APPENDIX C
PART ONE
TREATMENT COST ANALYSIS

INTRODUCTION

The purpose of this appendix is to present the methodology and data which were used to develop the national cost estimates presented in previous sections of this report. In this appendix, discrete unit costs for individual plants are described, based on existing in-place treatment.

It should be emphasized that the unit costs which are presented are for "idealized," "average" systems of given sizes and show only the incremental costs which would be incurred to meet the total trihalomethane (THM) regulation. In this report, the "average" water system for each size category was defined from the results of the 1976 Temple, Barker & Sloane survey of nearly 1,000 water systems around the country. This incremental approach assumes that an "average" treatment facility already exists, at least for chlorination (since these costs were used to cost out a THM regulation). The costs shown, then, are only the incremental costs required to change from that process to an alternative one. This approach does not take into account such local conditions as land availability, head loss through filter beds, etc.; and therefore, the costs calculated should only be applied to generate cost estimates for individual treatment plants if extreme caution is used.

Cost Information

METHODOLOGY

The methodology used to develop the cost inputs used in this appendix can be subdivided into the following three areas:

- Collection of capital and O&M cost information data
- Development of system cost information
- Verification of component costs

The remainder of this section will explore in detail the sources of information utilized in developing the cost estimates.

COLLECTION OF COST INFORMATION

The project approach used to obtain cost information is depicted in Figure C-1. Before initiation of the literature review, the components to be costed were determined. A list of these components is given in Table C-1. For each principal component on the list, a capital and operation and maintenance (O&M) cost had to be developed, while current average prices were needed for each subcomponent shown in Table C-2. The first phase of the collection of cost information was centered around a comprehensive literature review. From this review, which covered such journals as the Journal of the American Water Works Association, Ozone News, government publications, and other published sources of information, a comprehensive list of follow-on contacts was developed as was a set of published cost information.

Figure C-1

APPROACH USED IN OBTAINING COST INFORMATION

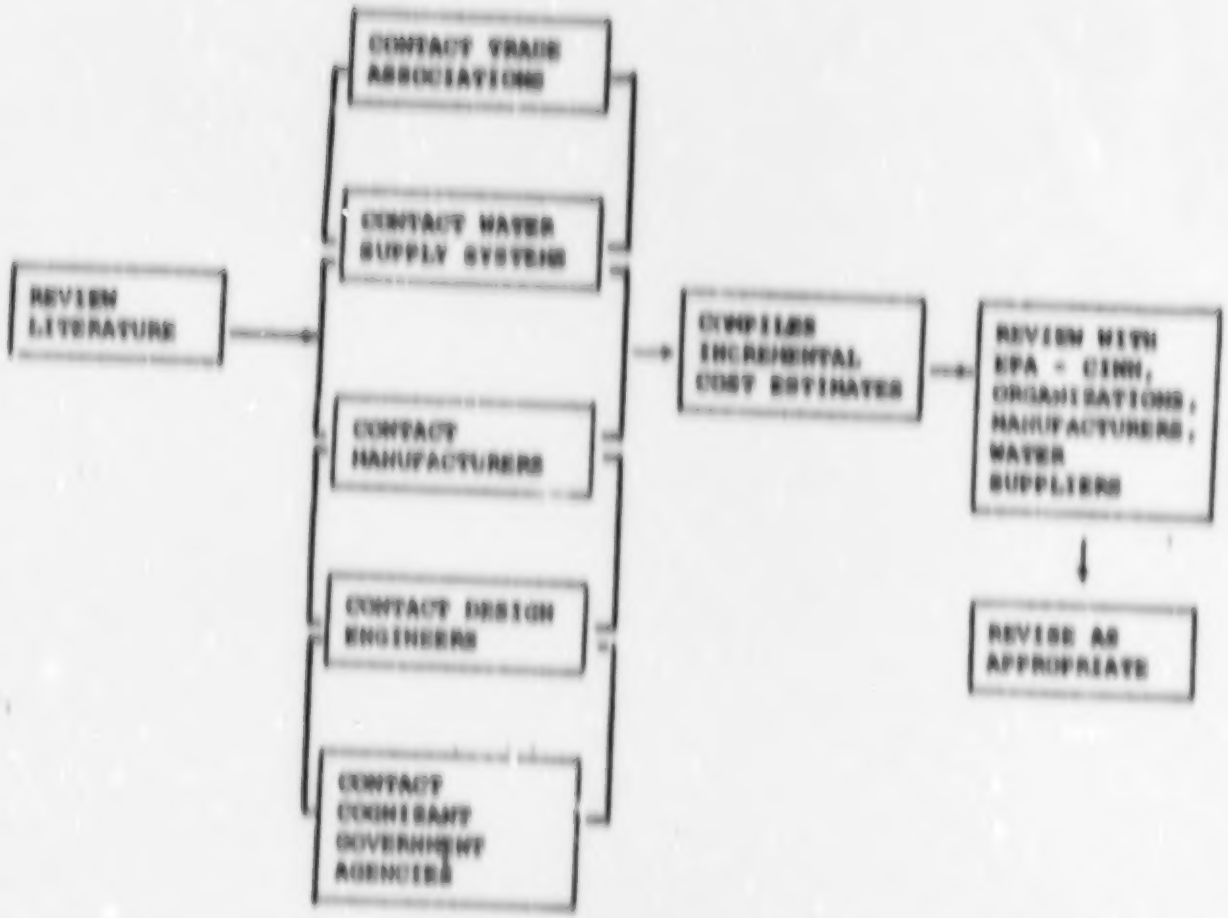

Table C-1

SYSTEM COMPONENTS FOR WHICH COST INFORMATION WAS NEEDED

Principal Components	Information Needed
Reactivation furnaces	Cost vs. size, throughput rates, operating parameters
Filter beds	Cost vs. size
Carbon transportation system	Operating parameters, cost, availability
Laboratory equipment	Operating parameters, costs
Contactors	Throughput, cost vs. size, operating parameters
Coagulation and sedimentation basins	Cost vs. size, operating parameters
Ozone generator and contactor	Cost vs. size, dosage rates, operating parameters
Ammonia feed pump	Cost vs. size
Chlorine dioxide generator	Cost vs. size, operating parameters

Table C-2

SYSTEM SUBCOMPONENTS FOR WHICH COST INFORMATION WAS NEEDED

Subcomponents		
Chemicals:	Chlorine	Availability, Cost, dosage rate
	Ammonia	
	Sodium chlorite	
	Carbon	
	Synthetic resins	
	Coagulants	
Electricity		Rates
Transportation		
Insurance		
Fuel		Fees
Labor		
Operating supplies		
Laboratory		

The sources of information identified in the literature review phase were then contacted in later phases of the task. Figure C-5 lists the carbon manufacturers who were contacted as well as a summary of relevant information. In addition to supplying information on granular activated carbon, many manufacturers also supplied information on regeneration furnaces and other useful information. In addition to this information, the following furnace manufacturers were contacted:

- Raymond Bartlett and Snow (rotary kilns)
- Nichols (multiple hearths)
- Shirco (electric ovens)
- Envirotech (multiple hearths)
- Vulcan (rotary kilns and fluidized beds)
- Stan Steel (rotary kilns)

For information on ozone generators, the Welsbach and Crane Corporations were contacted. Each manufacturer contacted was asked to supply product information, operation parameters, and cost information.

Table C-3 lists those treatment plants which were contacted to learn their experience and costs associated with granular activated carbon. These systems utilize GAC as a treatment for taste and odor control only. Unfortunately, none of these plants had on-site regeneration so actual operating costs and problems associated with this technology were available only from the waste water treatment facility at Lake Tahoe. The main information learned from these plants was mode of operation, cost of carbon, methods, and time requirements involved in removing GAC from the filter beds.

Table C-3

WATER TREATMENT PLANTS[a]

Contacted	Contacted
Pawtucket Water Filtration Plant Pawtucket, Rhode Island	Manchester Water Treatment Plant Manchester, New Hampshire
Davenport Water Company Davenport, Iowa	Danvers Water Treatment Plant Danvers, Massachusetts
Virginia American Water Company Hopewell, Virginia	Marinette Pumping Station Marinette, Wisconsin
Lawrence Filtration Plant Lawrence, Massachusetts	Terrebonne Waterworks Terrebonne, Louisiana
Huntington Water Corporation Huntington, West Virginia	Hamburg Water Treatment Plant Hamburg, New York
Water Filtration Plant Mt. Clemens, Michigan	Burlington Water Treatment Plant Burlington, Massachusetts
Bell City Water Treatment Plant Bell City, Oklahoma	Somerset Pumping Station Somerset, Massachusetts
Piqua Municipal Treatment Plant Piqua, Ohio	Watertown Water Treatment Plant Watertown, South Dakota
Amesbury Pumping Station Amesbury, Massachusetts	Bartlesville Water Department Bartlesville, Oklahoma
Scituate Water Treatment Plant Scituate, Massachusetts	Richmond Water Treatment Plant Richmond, Indiana

[a]Contacted during the period. Costs, operating parameters, etc.

DEVELOPMENT OF COST INFORMATION

The cost information developed from the previous task was collated and cost curves were developed. All costs were developed into 1978 dollars by applying the appropriate O&E News construction index factors. For each major construction component, capital and O&M costs were developed. Table C-4 shows the nine size categories for which costs were developed. Part Three of this appendix describes in detail the assumptions which were used in developing the costs.

Table C-4

SIZE OF TREATMENT PLANTS FOR WHICH COSTS WERE DEVELOPED

Category	Population Served	Average Plant Production (1,000 gal/day)	Average Plant Capacity (1,000 gal/day)
1	25-99	8	15
2	100-499	31	75
3	500-999	104	184
4	1,000-2,499	217	497
5	2,500-4,999	476	1,049
6	5,000-9,999	910	1,497
7	10,000-99,999	4,660	12,661
8	100,000-999,999	66,903	79,000
9	> 1 million	465,000	700,000

VERIFICATION OF COST INFORMATION

Figure C-1 illustrates the approach taken to verify all cost elements which were developed. The first step was to reconcile all costs with those developed independently by the EPA MERL Laboratory. There were some differences of opinion based on the different methodology used to calculate costs. The EPA has developed a treatment guide to estimate the total costs of applying treatment technology to control chloroform content in water. The EPA cost estimates assumed that the treatment technology would start from scratch rather than utilize existing facilities. This approach is reasonable for comparing costs on an equivalent basis rather than determining incremental costs for changing treatment processes which was the need in this analysis.

After the cost reconciliation with MERL, the assumed cost estimates were reviewed by the manufacturers, design engineers, and water supply system operators. The comments reviewed from these sources were then used in updating the cost estimates. The costs presented represent the consensus of opinion with respect to assumptions and costs. There are, however, some minor differences of opinion in certain cost areas.

Treatment Alternatives

INTRODUCTION

The purpose of this section is two fold:

- To describe the alternatives or additions to present water treatment practices which can be used to reduce the concentration of trihalomethanes.
- To describe the specific design parameters which lead to the unit cost for each treatment type.

The unit operations described in the following summary represent significant changes in current water treatment practices at the plant level which can minimize the formation of trihalomethanes. Before a plant considered these types of water treatment alternatives, it would try to modify existing practices such as the points of chlorination or coagulant types and dosages since this would involve no significant additional expenses.

In order to treat water to meet the proposed regulations for trihalomethanes, a number of treatment modes were considered. They included:

- Adsorption on granular-activated carbon.
- Disinfection with chlorine dioxide, ozone or ammonia, and chlorine (chloramines).
- Addition of coagulation and sedimentation.

The following is a description of the processes chosen. The description will include the necessary equipment, chemicals, and operator skills necessary to implement the treatment. The significant variables that affect the cost will also be outlined. The next section will detail the design utilized in this analysis to arrive at the unit cost.

ADSORBENTS

Granular activated carbon (GAC) was chosen as an adsorbent for the removal of the precursors of the trihalomethanes or the trihalomethanes themselves. The large surface area of activated carbon relative to particle size is responsible for its adsorption ability. There is also a good deal of information available from which to develop capital and operating costs. Other adsorbents such as resins can be used and promise to be viable options in the future, however, operating experience with resins is limited to pilot studies at present.

GAC can be used in place of mixed media as both a filter and as an adsorbent, and a medium to support biological oxidation. It can also follow filtration and be used strictly as an adsorbent and a medium to support biological oxidation. Presently, GAC (as well as powdered carbon) is used in water treatment for taste and odor control in the United States. The taste and odor causing compounds can be removed for two to three years or more before the GAC is spent and needs to be replaced. In meeting standards for trihalomethanes, however, the GAC would be spent in a shorter time, perhaps as little

as one to two months, depending upon water quality. After this time, trihalomethanes will begin to break through the filter. This considerably complicates the situation facing the managers of a water treatment plant. It forces them to consider the feasibility of on-site regeneration of the granular activated carbon. Regeneration of GAC is practiced on a large scale by carbon manufacturers, but it is not presently done at any water utilities.[1]

Placing GAC in conventional filters avoids the problem of modifying the hydraulics of a treatment plant in order to route the water through a set of contactors. There are four problems with placing GAC in existing filters however:

- The GAC needs to be regenerated sometimes as often as one to two month intervals and in most cases removing GAC from filters will require significant increases in the labor force to control THM.
- Filtration capacity is cut while the filter is out of service.
- Adsorption might not be optimal since the GAC is being used as a filter also.
- Filters might need to be redesigned to prevent loss of GAC during backwashing.

If contactors are used following filtration, a system designed solely for adsorption can be incorporated. Furthermore, the need for labor can be significantly reduced since the GAC can move automatically from the contactor to the regeneration furnace. However, there are significant additional capital expenditures for the contactor systems and also for plant modifications. The cost in modifying a plant is going to be site specific and there probably will be considerable variation from plant to plant. The need for additional space for

[1] *It should be noted that a side benefit of using GAC is the general reduction of organic chemicals, in addition to trihalomethanes. GAC could be used in anticipation of the Revised Primary Drinking Water Regulations, which may cover a broader range of organic chemicals.*

contactors plus the need to add pumping capacity to maintain hydraulic gradients are two costs that will depend on individual plant characteristics.

Which system a utility chooses is going to depend on a number of factors:

- Cost (both capital and operating).
- Performance of each system.
- Desire to expand labor force.
- Flexibility of system to meet the changes in operating conditions.

The decision will not be made until pilot testing has been completed and the necessary engineering studies performed.

Once a utility decides on GAC, it must choose whether to regenerate on-site or ship the GAC back to the manufacturer and purchase more. While the criteria for making the decision is the cost of GAC regenerated on-site versus GAC regenerated by carbon manufacturers, there are unknowns associated with determining these two results. Since carbon manufacturers will regenerate GAC in their own furnaces, they will offer GAC at a price which will attempt to recover the direct expenses of regeneration plus indirect expenses such as transportation to the regeneration facility and amortization of fixed expenses plus a profit. The price, therefore, could be anywhere up to the cost of virgin GAC. If the price were higher than virgin GAC, no one would be regenerating.

The cost per pound of GAC regenerated at a water treatment plant depends on many of the same factors as the cost to regenerate at a GAC manufacturing facility. The most

significant operating costs are GAC to make up for what is lost during regeneration, fuel cost to operate the furnace, and labor costs. In addition, the capital cost of the furnace which can run into millions of dollars has to be amortized over the GAC regenerated. The advantage a large regeneration facility has is that it benefits greatly from economies of scale. The capital cost per unit of carbon regenerated is much less for a larger furnace than a smaller one. Labor requirements for larger furnaces are not much greater than for smaller furnaces. The labor force at a facility that has been regenerating GAC for a period of time presumably has become familiar with the operation of the regeneration facility and this experience should be reflected in lower carbon losses during regeneration.

The more GAC that needs to be regenerated, the more favorable are the economics of regenerating on-site. Therefore, large treatment plants or treatment plants regenerating frequently will benefit more from on-site regeneration.

Furnaces

The types of furnaces that can be used to regenerate GAC include:

- Multiple hearths.
- Rotary kilns.
- Electric furnaces.
- Fluidized beds.

Most of the operating experience in carbon regeneration has been with multiple hearths. In order to develop representative costs, the analysis focused on multiple hearths. However,

the other types of GAC regeneration are being tested and could C-14
prove to be advantageous. Electric furnaces could prove useful for smaller installations. Fluidized beds are used in Europe for GAC regeneration and a number of manufacturers are developing them in the United States.

The last significant cost is the granular activated carbon itself. The initial fill is going to represent a significant expenditure. The price of GAC varies from $0.50 to $0.70 per pound. GAC can be manufactured from a number of raw materials, among them: coal, lignite, or coconut shells. This gives granular activated carbons different properties, such as hardness, and affects the types of organics which can be adsorbed.

In summary, if a water treatment incorporates GAC, it can do so in four possible ways.[1] The following matrix lists the major expenditures incurred by each of these alternatives. More precise descriptions including costs will be provided later. It should also be emphasized that with on-site regeneration, operators will have to be trained in the operation of a high-temperature furnace. This training is important since a malfunction in a furnace causing the loss of a large amount of GAC is a significant expense.

Monitoring requirements are two-fold:

- Check trihalomethane concentration.
- Determine when GAC is spent and when it is properly regenerated. Monitoring can be carried out by a state lab or by the water utility itself. While the costs are significantly less when the work is done by a state lab, the results are of little operational value. Large plants can be expected to do their own monitoring because of the seriousness of the problem and because of the cost implications of some treatments.

[1] *An additional use of GAC is in combination with ozone. This treatment has not been included as an alternative because of the lack of operating and cost information. However, new data will be forthcoming as a result of the experience in Europe with this treatment practice; it may prove to be a viable option for some systems.*

Table C-6

MAJOR CATEGORIES OF EXPENDITURES FOR EACH TREATMENT CHOICE

Treatment Choices[1]	Expenditures			
GAC in existing filters with on-site regeneration	Granular Activated Carbon	Significantly larger labor force	Regeneration furnace	Additional[2] filtration capacity
GAC in existing filters with off-site regeneration by carbon manufacturers	Granular Activated	Significantly larger labor force	Additional filtration capacity	Filter modification
GAC in contactors on-site regeneration	Granular Activated Carbon	Regeneration furnace	Contactors	Modification to plant hydraulics
GAC in contactors off-site regeneration	Granular Activated Carbon	Contractors	Modifications plant hydraulics	

[1] GAC with ozone not included because cost data is not yet available.

[2] Since the filters are out of service, presumably extra filtration capacity is necessary.

CHLORINE DIOXIDE

While granular activated carbon attempts to remove the precursors that react to form trihalomethanes or the trihalomethanes themselves, a disinfectant is still required in the treatment process. Chlorine dioxide has been found not to produce measurable quantities of trihalomethanes. Since it is as good a disinfectant as chlorine, and is a likely substitute since it leaves a residual, and is a much less expensive process than adsorption, it can be expected that some treatment plants will incorporate chlorine dioxide. The main drawback is the formation of chlorites which have come under some criticism for health effects reasons. EPA is recommending that, until further information becomes available, applications of chlorine dioxide should be limited to the 1-2 mg/l range.

Systems should control the total organic composition of the water so as to minimize demand for a chemical disinfectant. This practice will insure that the excessive amounts of chlorine dioxide, which can cause the formation of chlorites in large amounts, will not be needed.

Chlorine dioxide, which is already familiar to many water treatment plant operators, does not require significant capital expenditures. The only capital outlays are for:

- Generators
- Feed pumps
- Mixing tanks
- Piping
- Design

The operating costs consist of chlorine and sodium chlorite which are mixed in the generator yielding chlorine dioxide. In addition to uncertainty about dosage, the cost of sodium chlorite is a significant variable affecting the overall cost of the chlorine dioxide feed system. Since the use of chlorine dioxide replaces a system using chlorine alone, there will be some savings from a reduced chlorine dosage. Labor requirements are no different than those required for chlorination. Monitoring requirements would include testing for the level of chlorites as well as trihalomethanes.

OZONE

Ozone which would substitute for chlorine as a disinfectant is a highly capital intensive process. The necessary equipment includes:

- Generator
- Compressor dryers
- Piping and controls
- Contactors
- Design

Ozone can be generated by passing electricity through either air or pure oxygen. The operating costs consist mainly of electricity since it takes about 11 kilowatt hours to generate a pound of ozone. The major maintenance item in ozone production systems is the cleaning of dielectrics. These elements, exposed to constant heat and corona glow, become covered with solid deposits of poorly defined composition. Every two months dielectrics must be cleaned. This task can be performed by the present operators at the plant. The time devoted to maintaining ozone equipment should not be any greater than maintaining a chlorination system. Some chlorine would be saved since the ozone substitutes for chlorine. Since ozone does not leave a residual, it will be necessary to add a disinfectant, such as chloramines, chlorine, or chlorine dioxide, to water entering the distribution system.

One of the concerns with ozone is that although trihalomethanes are not formed, not much is known about the other by-products that will be formed as it oxidizes organic compounds in the water. In Europe, ozone is sometimes used prior to adsorption on granular activated carbon. Biological activity in the filter breaks down the organics that are adsorbed. Ozone is now being studied more closely in the United States, and in combination with carbon adsorption, might be used to reduce the concentration of organics and result in longer periods between required regeneration of the GAC.

The installation of an ozone system would require some operator retraining in the area of maintaining the generating equipment. In addition, ozone units present some occupational hazards as do most chemical feeding systems.

AMMONIA AND CHLORINE

Another alternative to chlorination is to substitute chloramines for free chlorine residual. In this case, the only capital costs incurred involve equipment for feeding ammonia including storage tanks, pumps, and piping. Operating costs are essentially the cost of ammonia.

One drawback to a chloramine system is that disinfection capability is sacrificed to some degree since the activity of chloramine is not as great as chlorine. However, since costs are low and little operator retraining is necessary, it is an attractive alternative to chlorination if proper disinfection can be maintained. Chloramines should be substituted for chlorine only after extensive microbiological testing in each system contemplating their use.

COAGULATION AND SEDIMENTATION

For some water systems, it might prove feasible to change from direct filtration to filtration preceded by coagulation and sedimentation. The advantage of this treatment is that it might be possible to remove some of the THM precursors during coagulation and sedimentation. This would avoid the necessity of employing granular activated carbon and would still allow for the use of chlorine.

Before this treatment methodology would be applied, it would be necessary to do extensive engineering jar testing to determine if the organics removal would be sufficient to warrant the additional costs.

The treatment methodology is well established, so this should pose no unusual constraint. The process does require additional manpower and it will be necessary to handle additional sludges due to the shift in treatment technologies.

SUMMARY

The various treatment alternatives can be arrayed against the following decision variables that will be used in selecting a specific treatment.

- capital expenditures
- operating costs
- familiarity of the utility with the treatment methods
- ability of each treatment method to limit production of trihalomethanes
- unknowns about the health effect consequences of incorporating specific treatments
- reduction of organics other than trihalomethanes

Some of the variables such as capital and operating expenditures are going to vary depending on the size of the system. What the individual utility must do is make tradeoffs within this list to come up with the optimum treatment.

SPECIFIC DESIGN PARAMETERS

GRANULAR ACTIVATED CARBON: CAPITAL EXPENDITURES

There are a number of capital expenditures that are incurred with GAC treatment. They include:

- initial carbon fill
- buffer carbon stock
- reserve carbon supply
- storage areas
- modification to plant hydraulics
- modification to filters
- carbon transportation systems
- regeneration furnace
- additional filtration capacity
- contactors
- instrument cost
- design

No treatment plant incurs all these expenditures. Some of the expenditures are specific to large or small plants, plants installing GAC in existing filter beds, and plants installing GAC in contactors following filtration.

In following the narrative, it will be helpful to refer to the unit costs developed for the nine size categories at the end of this section. For the purpose of clarity, some costs will be broken out.

Initial Carbon Fill

To determine the cost of the initial fill of granular-activated carbon, it was assumed that filtration rates would equal 1,150 gallons per day per cubic foot of carbon. This is equal to a filtration rate of 2 gallons per minute per square foot through 30 inches of granular activated carbon. Carbon density is equal to 28 pounds per cubic foot and the cost of granular activated carbon is $0.45 per pound. Carbon needs were sized for average-day production. The following table summarizes the design parameters used and the resulting unit costs. The cost of carbon itself was assumed to be uniform over all size categories.

Table C-6

AMOUNT OF COST OF INITIAL CARBON FILL

Design Capacity (MGD)	0.104	1.457	208.013
Average Day Production (MGD)	0.104	0.910	486.342
Granular Activated Carbon Needs (lb)[1]	8,301	90,570	10,973,000
Costs[2]	$1,000	$9,000	$4,937,850

[1]Assumes filtration rate of 1,150 gallons per day per cubic foot and a carbon density of 28 pounds per cubic foot.
[2]Assumes carbon cost of $0.45 per pound.

Buffer Carbon Stock

The buffer granular activated carbon supply assumes that an inventory of 10 percent of the initial carbon fill is purchased for all sized plants. This inventory is necessary

to replace GAC that is in the process of being regenerated on-site or returned to the manufacturer. Stock can also be held in the event of delivery problems or unexpected losses during regeneration. If this level of inventory proves too high, it can be reduced.

Reserve Carbon Supply

The cost for reserve carbon supply assumes that smaller systems which do not regenerate on-site have to purchase one year's supply or one truck load of carbon in order to qualify for a 25 percent discount on repeat carbon purchases. A discount is given since the manufacturer will regenerate granular-activated carbon and sell it back to the water industry.

Storage Area

For smaller systems that require a reserve carbon supply, a storage area will be necessary. Since the amount of GAC stored will be, at the most, on the order of 700 cubic feet, construction and materials costs should not exceed $2,000.

Modifications to Plant Hydraulics

If a water treatment plant installs contactors following filtration, the present configuration of the plant will have to be modified. Pumps will need to be installed to maintain the hydraulic gradient through the plant. In addition, construction and materials costs for piping will be incurred. The costs developed in this analysis were based partly on modifications of carbon adsorpt pump station costs used

in the Process Design Manual for Carbon Adsorption,[8] and partly from communication with plant engineers. For plants with a design capacity of 1.0 MGD or less, the analysis assumed about $50,000 per MGD. As plants increase in size, they benefit from economies of scale in construction, pump, design and piping costs. At the largest size categories, the estimated cost to modify the hydraulics was approximately $6,000 per MGD. It must be emphasized that there can be wide variability in these costs depending on pumping demands, extent of modification to present facilities, and land availability. However, the costs in the analysis should represent an average (mean) of the likely range of costs.

Carbon Transportation Systems

When carbon is used in place of mixed media, a system is necessary to move the carbon from the filter to either the regeneration furnace or a storage area for shipping back to a manufacturer. The system costed here would be similar to a series of ejectors such as those used by the Calgon Corporation to remove or introduce granular activated carbon to a filter. The larger plants might have a more elaborate system to cut down on labor. The costs for such a system start at $2,000; for larger plants requiring multiple ejectors, the costs would range up to nearly $1 million. The costs for representative plants are presented below in Table C-7. It can seem that larger plants enjoy economies of scale since the ejector systems can be run continually, moving from filter to filter. However, these costs are subject to large amounts of variation since there has been little thought as to how carbon can be moved from conventional filters on a regular basis.

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[8] *Process Design Manual for Carbon Adsorption*, U.S. Environmental Protection Agency, Technology Transfer, October 1973.

Table C-7

CARBON TRANSPORTATION SYSTEM

Plant Design Capacity (MGD)	Total Cost	Cost/Pound of Capacity
0.104	$ 0,000	$10,100
1.497	$ 3,400	$ 2,100
769.013	$965,000	$ 1,300

Specifying a regeneration furnace requires two types of information: the number of pounds of granular activated carbon that needs to be regenerated daily, and the amount of granular activated carbon that can be regenerated per square foot of capacity.

The amount of GAC regenerated on a daily basis is dependent on plant size and regeneration frequency. Regeneration frequency depends on the standard (MCL) that has to be met and trihalomethane or precursor concentration in the raw water. The daily amount of GAC that needs to be regenerated is the key input that determines whether regeneration will be on-site or whether it is more economical to ship the GAC back to the manufacturer. Variations in the amount of carbon regenerated daily can be seen in Table C-8 that follows.

Table C-8

GRANULAR ACTIVATED CARBON REGENERATED
(pounds/day)

Average Production (MGD)	Regeneration Frequency		
	45 Days	60 Days	75 Days
0.000	3,340	2,510	2,010
50.000	99,630	31,470	17,100
400.000	243,000	000	100,000

in the cost analysis, only plants over 5 MGD are assumed to regenerate on-site.

Based on information from carbon manufacturers and furnace manufacturers, the amount of carbon that could be regenerated per square foot of capacity was equal to 110 pounds per square foot of capacity. Representative multiple-hearth furnace costs are:

Table C-9

FURNACE COSTS

Hearth Area (sq. ft.)	Daily Regeneration Capacity at 110 Pounds per Day	Furnace Cost[1]
84	9,240	$ 300,000
37	4,070	$ 400,000
85	9,350	$ 575,000
193	21,230	$1,000,000
275	30,250	$1,200,000
442	48,620	$1,500,000
575	63,250	$1,700,000
845	92,950	$2,100,000

[1] These costs are for custom designed furnaces. Standard furnaces could be offered at some savings if there were enough demand for furnaces.

Additional Filtration Capacity

Additional filtration capacity is necessary if carbon is used to replace mixed media in a filter. Since the removal of carbon from most existing filters usually would be manual, the filter will be down for approximately three days each time carbon is removed for regeneration. Part of the time is spent chlorinating the filter before it can be

put back into service. Filtration costs for plants above 6 MGD were based on data from the "Monograph of the Effectiveness and Cost of Water Treatment Processes for the Removal of Specific Contaminants," by David Volkert and Associates. Design rate was assumed to be two gallons per minute or square foot. The costs included concrete structures, foundations, piping and underdrains, controls, designs and specifications, and construction overhead. Costs for smaller sized plants were developed by direct contact with manufacturers. Table C-10 that follows shows an example of the increase in filtration costs as regeneration cycles become more frequent.

Table C-10

FILTRATION COSTS

Design Capacity (MGD)	Regeneration Frequency		
	90 Days	60 Days	75 Days
10.665	$ 910,000	$ 180,000	$ 144,000
79.795	$ 750,000	$ 650,000	$ 520,000
720.913	$4,900,000	$3,050,000	$2,920,000

Modification to Filters

In developing costs for the replacement of the present media with granular activated carbon, expenditures will be incurred modifying the present filters. Since carbon is lighter than sand on a volume basis, it will be necessary to design the filter to prevent the loss of carbon on backwashing. Special supporting media such as gravel might need

to be added. In addition, labor expenditures need to be considered in the removal of the present media and the substitution of the granular activated carbon. The costs assumed in the analysis were approximately $5 per square foot of filter area. At average day production, the analysis assumed the plant was operating at a filtration rate of two gallons per square foot per minute. The amount of the filter area required for each size category can then be determined.

Contactors

Contactor costs for plants above 1 MGD were developed from the Process Design Manual for Carbon Adsorption updated for inflation.

The assumptions for the contactor system follow:

Table C-11

CONTACTOR SYSTEM SPECIFICATIONS
(MGD)

Plant Production (MGD)	0.660	00.992	000.342
Number of Contactors	4	10	60
Hydraulic Loading (gal/min/sq. ft.)	0	0	0
Diameter of Contactors (ft.)	15	20	30
Depth of Contactors (ft.)	10	10	10
Volume of Granular Activated Carbon (cu. ft.)	1,766	4,906	7,065
Apparent Contact Time (min)	0.0	0.0	0.0
Water Filtered (gal/day/cu. ft.)	1,160	1,160	1,160

For smaller sized plants, prices for pressure filtration units were used. Contactors were designed for average day production. When production increases, more contactors can be added. The type of contactor costed for larger systems is an upflow counter-current packed bed.

Instrument Costs

The cost of equipment and accessories to analyse for chloroform is estimated in the range of $10,000 to $15,000. The average is about $14,000. The instrument is a gas chromatograph capable of processing from six to possibly twenty samples in a working day, depending upon the analytical procedure selected. It should be noted that the $14,000 is somewhat conservative. Some systems may select the less expensive analytical procedure and thus reduce their instrumentation costs below $14,000.

Engineering Design Costs

In order to incorporate these changes in an existing treatment plant design, costs have to be considered. For the purpose of this analysis, the design costs were drawn from a series of cost curves published by the American Society of Civil Engineers. The fees range from 5.7 percent for projects over $100 million up to 11.6 percent for projects in the range of $100,000. For smaller projects less than $50,000, a 30.0 percent rate was used.

The design fees for the nine sized plants regenerating every 60 days are as follows:

Table C-12

DESIGN FEES FOR INCORPORATING GAC ADSORPTION

Plant Size (MGD)	Capital Costs ($)	Design Fees ($)
.015	8,490	500
.075	101,116	8,424
.100	81,163	6,233
.357	66,429	6,164
1.000	103,926	11,926
1.457	180,184	16,820
12.666	1,661,608	125,089
28.790	5,126,065	363,990
700.013	84,006,813	1,611,737

GRANULAR ACTIVATED CARBON: OPERATING COSTS

There are a number of operating costs associated and incurred with GAC tratment. They include:

- operating costs for adsorber (contactor)
- operating costs for regeneration including:
  - --labor
  - --maintenance labor and materials
  - --operating supplies
  - --fuel costs
  - --carbon replacement
  - --insurance for furnace
- operating costs for GAC in Filter

Operating Costs for Contactor

Operating costs for the contactor include power, labor and maintenance materials. The costs in the analysis were developed from the Process Design Manual for Carbon Adsorption. The following table lists the operating costs for the larger sized plants.

Table C-11

CONTACTOR OPERATING COSTS

Plant Production (MGD)	0.868	86.832	485.342
Maintenance Material	$ 1,000	$ 10,000	$ 100,000
Labor	10,000	40,000	110,000
Power	10,000	100,000	1,000,000
Total	$20,000	$150,000	$1,000,000

Operating Costs for Regeneration

Carbon regeneration on-site will incur a number of operating expenses including:

- labor
- maintenance labor and materials
- operating supplies
- fuel costs
- carbon replacement
- insurance for furnace

Labor costs for furnaces serving plants of approximately 50 MGD assumed 5 operators and 1 foreman would be needed. Wage rates would equal $7 to $10, respectively, for a weighted average rate of $7.50. For plants producing about 485 MGD, about 14 people would be needed in total. Plants producing around 8.7 MGD would need 3 people.

Maintenance Labor, Materials and Operating Supplies--Maintenance labor and materials (MLM) were estimated at 5 percent of the furnace cost while operating supplies were about 10 percent of MLM.[4]

[4] Hutchins, R.A., "Thermal Regeneration Costs," Chemical Engineering Progress 71(8).

Fuel Costs--Fuel costs consist of those for electricity and for oil or natural gas for the furnace. The costs depend on the amount of carbon regenerated daily, as the following chart indicates.

Table C-15

Fuel Costs

Carbon Regenerated Daily (lb)	Fuel Costs Yearly	Fuel Cost/lb. Carbon Regenerated
2,500	$ 19,000	$0.022
21,000	$ 185,100	$0.017
100,000	$1,100,000	$0.017

The requirements for the various utilities necessary for carbon regeneration are:

Table C-16

Utility Requirements

Carbon Regenerated Daily (lb)	Steam (lb/lb)	Electricity (kwh/lb)	Fuel (kBTU/lb)
2,000	0.6	.035	5,000
10,000	0.6	.011	4,300
70,000	0.6	.004	3,700

Carbon Replacement--Carbon loss on regeneration can be the most significant operating cost factor. The analysis assumes a 7 percent carbon loss. Carbon can be lost to abrasion during transportation to the furnace and it can be oxidized to carbon dioxide in the furnace. If carbon losses can be cut, it can have a significant effect on costs. The following table shows the results of various carbon losses for a regeneration frequency of once every 60 days.

Table C-16

CARBON LOSS

Carbon Loss (%)	Average Daily Production (MT/d)	Cost ($/year)
3	681	$ 889,660
6	681	$1,661,000
7	681	$2,174,000
10	681	$2,961,000

Insurance for Furnace--Approximately 1 percent of the capital cost of the regeneration furnace is allocated to insurance costs.

Operating Costs for GAC in a Conventional Filter

Labor for Filter--Since carbon often cannot be automatically ejected from a conventional filter, a large labor force usually is required. The amount of carbon that needs to be removed from a filter depends on regeneration frequency. Assuming a 60-day regeneration frequency, the amount of carbon that needs to be transported yearly for various sized plants is:

Table C-17

CARBON TRANSFER LABOR

Average Daily Production (MGD)	Carbon (lb)	Labor Costs[1]	Number of Laborers	Pounds Carbon Moved Per Day Per Laborer[2]
.010	122,400	$ 100	1*	825
0.066	816,000	$1,700	1	1,925
56.993	7,130,000	$12,000	15	2,350
665.367	65,660,000	$42,120	63	6,667

[1]Assumes $7.00 per hour wage rate.
[2]Assumes each laborer works 235 days per year.
*Part-time.

The increase in productivity for the larger size plants is due to more automated ejection equipment.

Operating Costs for Scour and Transport System--Operating costs for scour and transport system is estimated at 5 percent of the capital expenditure for this system.

Laboratory Control Analysis--For systems up to 1 MGD it was assumed that a state laboratory would take care of the quarterly monitoring requirement for trihalomethanes. Larger utilities would hire a chemist whose principal responsibility would be to make sure regeneration was being done properly and at the correct times. The salary of the chemist was assumed to be $17,000 per year including fringe benefits.

CHLORINE DIOXIDE:
CAPITAL EXPENDITURES

Research into the production of trihalomethanes has suggested that if chlorine dioxide is substituted for free chlorine, trihalomethane production can be minimized. The precursors of the trihalomethanes are not removed, but virtually no trihalomethane forming reaction occurs. The attractiveness of chlorine dioxide lies in both the familiarity of the water industry in using the chemical, and in the significantly lower cost of operating such a system when compared to the cost of AC adsorbent. It should be realized that the following costs are estimates and some plants might have to spend more, other plants less. Some utilities with chlorine dioxide equipment available will spend nothing.

The capital cost components are:

- generators
- feed pumps
- mixing tanks
- installation charges
- design costs

Generators

Costs for three different generator sizes were used in the analysis:

[illegible] size
generator costs

[illegible] capacity (lb/hr)	Costs
1,017	[illegible]
79,700	$1,000
105,511	$7,170

These costs represent what the approximate expenditures would be to serve systems up to these sizes. The more expensive generators can accommodate a larger flow rate. Generator costs were developed from manufacturers' data.

Feed Pumps

Sodium chlorite feed pumps range in price from $300 to $600. One pump is sufficient to serve the chemical needs of a plant up to 90 MGD. Beyond this size, multiple pumps are necessary. The analysis assumed a $300 pump was capable of

feeding sodium chlorite to the smallest generator. The $400 pump would feed the larger generators. Pumps were sized on the basis of head requirements and the flow rate of sodium chlorite that would be needed. Pump costs were supplied by manufacturers.

Mixing Tank

Various sized mixing tanks, which are of a fiberglass reinforced plastic material, were costed to store sodium chlorite. Dry sodium chlorite is purchased for tanks used in plants up to 50 MDG. Liquid sodium chlorite is used in the largest sized plants. The largest sized tank can hold about 32,000 gallons of 50 percent sodium chlorite--about 3 weeks supply at a dosage of 1.5 pounds per minute of chlorine dioxide.

Installation

Installation costs are estimated only for the work of outside contractors. Mechanics' and operators' time for readjustment of piping within the treatment plant was not included.

Design costs should also be incorporated into this analysis. Due to the small amount of capital expenditures involved for chlorine dioxide generation, it is assumed that the design fee would be approximately 20 percent. This fee was adopted from suggested rate supplied by the American Society of Civil Engineers.

SUMMARY OF CAPITAL COSTS
FOR GAC AND CHLORINE DIOXIDE

It is interesting to compare the capital costs for chlorine dioxide with GAC as shown in Table C-18.

Table C-19

COMPARATIVE CAPITAL COSTS: CHLORINE DIOXIDE AND GAC

Design Capacity (MGD)	Chlorine Dioxide Capital Costs ($)	GAC Capital Costs ($)
.010	600	2,000
.025	800	14,662
.100	2,264	37,396
.457	3,044	64,693
1.040	3,303	116,312
1.457	3,303	800,004
10.000	20,298	1,600,697
28.770	60,760	5,449,725
700.013	37,874	25,607,350

[1] GAC in contactors, 60-day regeneration cycle.

For the largest sized plants, the capital expenditures for chlorine dioxide are on the order of 0.1 to 0.3 percent of the costs for GAC.

CHLORINE DIOXIDE: OPERATING COSTS

Operating costs for chlorine dioxide treatment consist primarily of the purchase of sodium chlorite and chlorine. Chlorine is mixed at a ratio of 1 to 2 pounds of technical grade chlorite. A dosage of 1.5 ppm chlorine dioxide was chosen for this analysis; the operating costs and assumptions are summarized in Table C-20.

For the two smallest sized plants, anthium dioxide was chosen as a source for chlorine dioxide. When released into a solution containing chlorine or a solution at a pH at 6.0, anthium dioxide will release chlorine dioxide. Although anthium dioxide is about twenty times as expensive as sodium chlorite, it avoides the problem of mixing chlorine and sodium chlorite in a generator to produce chlorine dioxide.

Table C-60

OPERATING COSTS FOR CHLORINE AND SODIUM CHLORITE

Plant Production (MGD)	Sodium Chlorite Usage (lb/year)	Sodium Chlorite Cost ($/year)	Chlorine Usage (lb/year)	Chlorine Cost* ($)
.104	630	630*	320	70**
.217	1,314	1,314*	671	166
.476	2,880	2,710	1,605	361
.910	5,574	5,162	3,450	691
2.666	40,600	32,309*	25,305	2,530**
26.993	395,192	276,918	215,385	21,538
405.362	2,947,773	1,827,619*	1,842,857	150,865**

*Assumes sodium chlorite cost of $1.00, $0.84, $0.80, $0.62 per pound of 100 percent sodium chlorite respectively.

**Chlorine cost of $0.20, $0.10, $0.07 per pound respectively.

Plants producing up to 300,000 gallons per day are assumed to be too small to efficiently use existing chlorine dioxide generating equipment.

Monitoring

The monitoring assumptions are the same as for carbon adsorption. Plants up to 1 MGD would send their samples to a state lab to be analyzed on a quarterly basis. Plants above 6 MGD would employ a chemist. Part of his duties would be to ensure that chloroform is not produced. The chemist's salary is assumed to be $7,000 per year.

Chlorine Saved

Since chlorine dioxide replaces chlorine as a disinfectant, a credit should be subtracted from the chlorine dioxide costs to account for these savings. The amount of chlorine and dollar savings can be quite significant for large systems:

Table C-61

CHLORINE SAVINGS

Average Production (MGD)	Chlorine Savings (lb/year)*	Chlorine Savings ($)
.006	79	16**
.031	405	75
.109	1,390	255
.017	2,570	530
.076	6,910	1,160
.010	11,050	2,220
5.666	82,705	8,185**
55.933	707,060	69,474
405.348	5,023,100	414,200**

*Assumes a 4 mg/l chlorination system is replaced.
**Assumes chlorine costs of $0.20, $0.10, $0.07 per pound respectively.

OZONE:
CAPITAL EXPENDITURES

Ozone does not form chloroform upon reaction with the precursors of the trihalomethanes. For this reason, it is considered a potential substitute for chlorine. However, since ozone dissipates almost immediately, provision has to be made for a residual disinfectant in the distribution system.

The components of the capital costs for an installed unit are:

- generator
- piping, controls and enclosure
- contactors
- installation

The capital costs for ozone were developed with the aid of cost curves from the "Monograph of the Effectiveness and Cost of Water Treatment Processes for the Removal of Specific Contaminants,"[5] and are updated for inflation. For the two smallest sized plants, data was supplied by the Crane Company. The total capital costs for completely installed ozone units are:

Table C-22

OZONE CAPITAL COSTS

Design Capacity (MGD)	Cost of Complete Unit*	Cost per MGD of Capacity
.018	$ 4,560	$303,000
.076	$ 7,630	$100,400
.184	$ 18,282	$ 99,350
.457	$ 35,515	$ 77,700
1.056	$ 65,080	$ 61,600
1.457	$ 82,780	$ 56,800
12.065	$ 401,340	$ 33,700
79.790	$1,530,200	$ 19,300
726.013	$7,726,415	$ 10,600

*Assumes unit sized for maximum day to deliver 2 mg/l. Cost includes all capital expenditures.

The economies of scale for larger sized plants are immediately evident from these figures.

There are additional capital costs associated with the maintenance of a residual throughout the distribution system. They are covered below along with the design fees for integrating an ozone system into an existing plant.

[5] *David Volker and Associates.*

Additional Capital Costs

Ammonia Feed Pump and Tank--Since ocunation will requires a residual in the distribution system to control after-growths of bacteria, a system has been costed to add ammonia to chlorine to form chloramines. A residual of 0.0 ppm of chloramines has been assumed. The cost for feed pumps and tanks are:

Table C-23

FEED PUMP AND TANK COSTS

Design Capacity (MGD)	Cost
.015	$ 400
.075	$ 400
.108	$ 680
.457	$ 680
1.058	$ 730
1.457	$ 730
12.065	$ 1,600
79.790	$ 2,000
796.013	$14,000

Monitoring Instrument--The three largest sized plants are assumed to purchase a gas chromatograph for $14,000 to analyze for trihalomethanes; there is a possibility of the occurrunce of trihalomethanes in a chlorine-ammonia system. To avoid this, close monitoring and control of the process is necessary.

Design Fees--In order to incorporate modification for ...one in an existing treatment plant, design costs must also be includ...d. For the purpose of this analysis, ... design costs were drawn from a series of cost curves published by the American Society of Civil Engineers. The fees range from 8.7 percent for projects over $100 ...tion up to 11.6 percent for projects in the ... range of $100,... For small projects less than $50,000, a rate of 20 percent of capital costs was used.

The design fees for the nine sized plants are as follows:

Table C-24

DESIGN FEES FOR INCORPORATING OZONE

Plant Size (MGD)	Capital Costs	Design Fees
.010	$ 9,004	$ 991
.075	$ 7,930	$ 1,586
.100	$ 16,057	$ 3,791
.457	$ 36,194	$ 7,239
1.040	$ 65,019	$ 8,876
1.467	$ 83,516	$ 10,867
10.665	$ 419,045	$ 35,510
99.790	$1,584,291	$108,000
426.013	$7,784,414	$480,774

OZONE: OPERATING COSTS

The operating costs for ozone consist primarily of electricity, since 10.5 kwh are needed to generate a pound of ozone. There are additional costs for the ammonia, chlorine, and monitoring.

The costs and amounts of electricity necessary are:

Table C-25

ELECTRICITY REQUIREMENTS

Design Capacity (MGD)	Kilowatt-Hours per Year[1]	Cost
.006	190	$ 5*
.031	990	$ 30
.104	3,330	$ 105
.207	6,625	$ 210
.476	15,230	$ 790
.910	29,120	$ 930
6.666	213,310	$ 6,830
30.993	1,023,800	$ 35,480**
485.342	15,530,950	$310,620

[1]Assumes 10.5 kwh per pound of ozone and a 1 mg/l dosage.

*Assumes electricity cost of $.030/kwh.

**Assumes electricity cost of $.02/kwh.

Since ozone replaces chlorine, the treatment should be credited with the chlorne savings. The analysis assumed 2 mg/l were saved since the plant was originally using 4 mg/l and now needs only 2 mg/l to add to ammonia forming a chloramine residual in the distribution system. The cost savings are:

Table C-26
CHLORINE SAVINGS

Average Production (MGD)	Chlorine Saved Per Year (lb)	Cost Savings
.006	37	$ 7
.031	190	$ 36
.104	625	$ 125
.207	1,325	$ 265
.476	2,900	$ 580
.910	5,550	$ 1,110
4.666	40,640	$ 4,064
56.993	347,430	$ 34,743
485.342	2,960,430	$207,090

Ammonia

Ammonia is added at a rate of 1 to 3.5 to the chlorine to form chloramines. The costs are:

Table C-27
AMMONIA COSTS

Average Production (MGD)	Ammonia Added per Year (lb)	Ammonia Cost[1]
.006	10	$ 1.15
.031	75	$ 9.00
.104	850	$ 20.00
.207	700	$ 85.00
.476	1,040	$ 125.00
.910	2,000	$ 240.00
4.666	11,590	$ 1,390.00
56.993	90,910	$ 11,070.00
485.342	837,500	$101,000.01

[1] Assumes $240 per ton.

Monitoring

Small systems will send out samples for analysis on a quarterly basis while large systems will hire a chemist to perform the control analyses. The chemist's annual salary is assumed to be $17,000.

AMMONIA AND CHLORINE: CAPITAL EXPENDITURES

Another possibility to minimize trihalomethane production is to simply use chloramines as a disinfectant. The disinfecting capability is less than for chlorine alone. However, a 15 minute contact time with free chlorine might provide sufficient disinfection without producing trihalomethanes.

The capital costs for equipment consists of:

- distribution system,
- pumps and controls, and
- design fees

A distribution system was costed for larger plants since it is possible that ammonia might have to be fed at the intake or at a point distant from the central facility where the rest of the chemicals are fed. The analysis assumed a piping cost of $11.85 per linear foot.

Pumps, controls, and storage tanks are similar to the ammonia system costed in the case analysis. The expense ranges from $600 to $31,000 for the largest system.

Design costs would be about 80 percent of the capital cost; since this treatment has a low capital cost, the design fees are relatively low.

AMMONIA AND CHLORINE: OPERATING COSTS

Operating costs consist of chlorine, ammonia, and the associated monitoring.

Additional chlorine is required since the disinfecting capability of chloramines is less. Ammonia is also required. The dosages and costs of these two chemicals are:

Table C-28

CHLORINE AND AMMONIA COSTS

Average Production (MGD)	Chlorine Dosage[1] (lb/year)	Ammonia Dosage[2] (lb/year)	Chlorine Cost[3] ($)	Ammonia Cost[3] ($)
.006	75	20	15[4]	2
.031	385	110	75	13
.106	1,290	370	225	44
.207	2,570	735	530	90
.476	5,910	1,690	1,160	200
.910	11,290	3,225	2,220	380
6.666	82,725	23,630	16,120[4]	2,790
56.993	707,280	202,080	69,479	23,800
486.347	6,033,100	1,720,890	414,200[4]	202,600

[1]Assumes 4 ppm dosage.
[2]Assumes 1.15 ppm dosage.
[3]Ammonia cost $0.12 per pound.
[4]Chlorine at $.20, $.10, and $.07 per pound respectively.

Monitoring costs are $100 per year for systems up to 1.5 MGD. This consists of sending quarterly samples to a state laboratory for analysis. Large systems will hire a chemist who can perform trihalomethane analyses and also recommend proper dosages of the ammonia and chlorine in order to minimize trihalomethane production while properly disinfecting the water.

COAGULATION AND SEDIMENTATION; CAPITAL EXPENDITURES AND OPERATING COSTS

It is well documented in the literature that coagulation can successfully remove suspended organic matter. For this reason, the costs of adding a coagulation/sedimentation system to an existing direct filter have been included. In developing these costs, the principal capital costs are for the construction and set up of the units. For systems treating less than 1 MGD, it was assumed that package treatment plants would be utilized, while for larger systems, individually designed and engineered systems would be used. All systems were designed for capacity flow although they were considered to operate at average daily production levels.

The capital and O&M costs for three system sizes are shown in the following table.

Table C-29

CAPITAL AND OPERATING COSTS FOR COAGULATION AND SEDIMENTATION
(dollars in thousands)

System Size (MGD)	0.104	1.497	129.013
Capital Costs	43.6	298.5	32,063.7
O&M Costs/Year	9.5	40.5	6,820.7

Among the operating cost items, labor to operate the facility is the most significant for systems producing less than 1 MGD; for the largest plants, the costs for coagulants, electricity, and maintenance supplies are the most prominant. The costs of these items by plant size are listed below

Table C-30

OPERATING COST ITEMS

System Size (MGD)	0.184	1.457	728.013
Labor	$7,300	$91,400	$ 270,700
Chemicals	$ 600	$ 5,000	$2,670,300
Electricity	$1,200	$10,600	$3,543,000
Other	$ 400	$ 2,900	$ 320,600

The discussion in Part Two of this Appendix (Sensitivity Analysis) summarizes the changes in the total cost for each treatment category which would result from changes to those cost items which are most subject to variability.

COST DATA SHEET

Technology: [illegible]	System Size (mgd)								
Regulation: [illegible]	1	2	3	4	5	6	7	8	9
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
I. Basic Costs									
1. Capital Cost (Single)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2. O/M Cost (EIC/EIA plus)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
without AFU control analysis									
with AFU control analysis									
II. Capital Cost Detail (Elements)									
1. Initial Carbon Fill	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2. Buffer Carbon Stock	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3. Reserve Carbon Supply	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			
4. Storage Area	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			
5. Carbon Transportation System			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6. Regeneration Facility							[illegible]	[illegible]	[illegible]
7. Additional Filtration Capacity	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8. Chlorination Instruments							[illegible]	[illegible]	[illegible]
9. Modification of Existing Filters	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SUBTOTAL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
III. Engineering/Design Fee	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TOTAL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
III. O/M Cost Detail (Elements/Item)									
1. Labor									
a) Operating Labor for Filter	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
b) Operating Labor for Furnace							[illegible]	[illegible]	[illegible]
2. Chemicals									
3. Electricity									
4. Other									
a) Carbon Replacement	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
b) Maintenance Labor & Materials for Furnace							[illegible]	[illegible]	[illegible]
c) Operating Supplies for Furnace							[illegible]	[illegible]	[illegible]
d) Fuel Costs for Furnace							[illegible]	[illegible]	[illegible]
e) Operating Costs for Solids Transport System			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
f) Insurance for Furnace							[illegible]	[illegible]	[illegible]
g) Laboratory Chemical Analyses	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TOTAL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

COST DATA SHEET

Technology: [illegible]	System Design								
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2. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
without [illegible]									
with [illegible]									
II. [illegible]									
1. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			
4. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			
5. [illegible]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6. [illegible]							[illegible]	[illegible]	[illegible]
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8. [illegible]							[illegible]	[illegible]	[illegible]
9. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Subtotal	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TOTAL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
III. [illegible]									
1. Labor									
a) [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
b) [illegible]							[illegible]	[illegible]	[illegible]
2. Chemicals									
3. Electricity									
4. Other									
a) [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
b) [illegible]									
[illegible]							[illegible]	[illegible]	[illegible]
c) [illegible]							[illegible]	[illegible]	[illegible]
d) [illegible]							[illegible]	[illegible]	[illegible]
e) [illegible]									
[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
f) [illegible]							[illegible]	[illegible]	[illegible]
g) [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TOTAL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

COST DATA SHEET

[illegible]	SYSTEM SIZE (mgd)								
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II. [illegible]									
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2. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SUBTOTAL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TOTAL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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2. [illegible]									
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b. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
c. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
d. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TOTAL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

COST DATA SHEET

[illegible]	[illegible]								
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II. [illegible]									
1. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	–	–	–
4. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	–	–	–
5. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7. [illegible]	–	–	–	–	–	–	[illegible]	[illegible]	[illegible]
8. [illegible]	–	–	–	–	–	–	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
III. [illegible]									
1. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2. [illegible]									
a) [illegible]	–	–	–	–	–	–	[illegible]	[illegible]	[illegible]
b) [illegible]	–	–	–	–	–	–	[illegible]	[illegible]	[illegible]
c) [illegible]	–	–	–	–	–	–	[illegible]	[illegible]	[illegible]
d) [illegible]	–	–	–	–	–	–	[illegible]	[illegible]	[illegible]
3. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4. [illegible]	–	–	–	–	–	–	[illegible]	[illegible]	[illegible]
5. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

COST DATA SHEET

[illegible]	[illegible]								
[illegible]	1	2	3	4	5	6	7	8	9
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
I. [illegible]									
1. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
II. [illegible]									
1. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	–	–	–	–
4. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	–	–	–	–
5. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7. [illegible]	–	–	–	–	–	–	[illegible]	[illegible]	[illegible]
8. [illegible]	–	–	–	–	–	–	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
III. [illegible]									
1. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2. [illegible]									
a) [illegible]	–	–	–	–	–	–	[illegible]	[illegible]	[illegible]
b) [illegible]	–	–	–	–	–	–	[illegible]	[illegible]	[illegible]
c) [illegible]	–	–	–	–	–	–	[illegible]	[illegible]	[illegible]
d) [illegible]	–	–	–	–	–	–	[illegible]	[illegible]	[illegible]
3. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4. [illegible]	–	–	–	–	–	–	[illegible]	[illegible]	[illegible]
5. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

COST DATA SHEET

CALCIUM HYDROXIDE CALCIUM/MAGNESIUM HYDROXIDE	SYSTEM CODE (mgd)								
	1 [illegible]	2 [illegible]	3 [illegible]	4 [illegible]	5 [illegible]	6 [illegible]	7 [illegible]	8 [illegible]	9 [illegible]
I. [illegible]									
1. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
II. [illegible]									
1. [illegible][a]							[illegible]	[illegible]	[illegible]
2. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3. [illegible]							[illegible]	[illegible]	[illegible]
SUBTOTAL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TOTAL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
III. [illegible]									
1. Labor									
2. Chemical									
a. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
b. [illegible][b]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3. Electricity									
4. Other									
a. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TOTAL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
IV. [illegible]									
1. Type of Equipment									
2. Labor Required									
3. Chemicals									
a. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
b. [illegible]									
c. [illegible]									

[illegible]

[a] [illegible]

[b] [illegible]

COST DATA SHEET

CODULATION AND DESIGNATION	SYSTEM SIZE (mgd)								
	1 .015 (.013)	2 .05 (.031)	3 .1 (.06)	4 .2 (.12)	5 .5 (.3)	6 1 (.5)	7 2 (1)	8 5 (3)	9 10 (6)
I. Plastic liners									
1. Capital Cost ($/mgd)									
1. O&M Cost ($/1000 gallons)									
II. Capital Cost Detail ($/system)									
1. Clay & Sealer, Liners Cover									
2. Synthetic Cover									
TOTAL									
III. O&M Cost Detail ($/system/year)									
1. Labor[b]									
2. Chemicals									
a. Alum, $Al_2(SO_4)_3$[c]									
b. Polyelectrolyte ($/lb)[d]									
3. Electricity[e]									
4. Other									
a. Maintenance Supplies									
b. 4% of plant cost (lining parts, valves, etc)									
TOTAL									
IV. Assumptions									
1. Type of Equipment	a	a	a	a	a	a	a	a	a
2. Labor Requirement									
3. Chemicals									
a. Coal/Fuel									
b. Powerline									
c. Initial Fill, pounds/mgd	Fuel adjustment								

Other assumptions:

Packaged water treatment plant including fluid mixing chamber, flocculation chamber, settling chamber, and sludge.

Pumping lines, pipe fitting, valves, electrical hookups, fittings, labor, etc.

Pumping and engineering and construction costs.

Assumes 30 gpm weight mix.

Assumes 60 gpm weight mix.

Type of equipment assumed, i.e., as three or self-installed.

Assumes 2 units/100 gals mineral water and 0.2 mmol/l for class 1-7 and 2 mmol/l for class 8-9.

Assumes a labor rate of $10/hr for operators and $15/hr for supervisor.

APPENDIX C
PART TWO
SENSITIVITY ANALYSIS OF TREATMENT COSTS

INTRODUCTION

In order to estimate the national economic impact of the proposed organic regulations the costs of adding the necessary treatments had to be developed for water systems in each of nine size categories. The costs which were used in the foregoing analysis and described in Part One of Appendix C represented the average expenditure which a system would incur when installing a unit treatment process to meet a particular regulation. Clearly there would be variations from the average cost. The purpose of Part Two of this Appendix is to document which costs are most likely to vary and to illustrate the sensitivity of the total cost for each treatment to changes in those line items.

During the development of the treatment costs, ERCO/TBS had identified certain capital or operating items which dramatically affected the total costs; regeneration frequency, contactor sizes, and chemical dosages and prices were among the most critical assumptions. Other items which are directly affected by site-specific conditions included such expenditures as those required for hydraulic modifications. In order to verify the selection of the most variable costs and to obtain estimates of the range of variability, ERCO/TBS visited four large systems which had examined some of these costs.[1] The conclusions from these visits are reflected in the selected costs and cost ranges which follow.

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[1] *Documented in "Analysis of Drinking Water Treatment Costs and Implementation Issues: Four Case Studies" 8/77 (TBS, ERCO)*

The discussion which follows covers the results of the sensitivity analyses on two categories of treatments:

- Carbon adsorption - either as a replacement for media in existing filterbeds or following filtration in contactors
- Changing the disinfection process - using ozone, chlorine dioxide or chloramines

The analyses include the effects on costs for the three largest size categories of water systems;[2] the results are presented in the following sections:

- Approach
- General Findings
- Individual Treatment Analyses
- Summary of Most Significant Cost Items

Approach

The first of three steps used in this analysis is to present the base costs[3] for each treatment for purposes of comparison in terms of dollars per million gallons of water treated. For instance, in Table C-31 on page C-62, for a system producing an average of 6.7 MGD the base total cost for adding granular activated carbon adsorption is $120 per million gallons. This includes $76 of operating and maintenance costs and $44 of capital costs. The capital costs were determined by amortising the total capital cost of $1,080,308 at 10 percent per year and allocating that number number over average production during the year. Operating costs were determined by allocating the yearly operating costs of $184,730 over average daily production.

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[2] *Population served: 10,000-100,000; 100,000-1 million; over 1 million*

[3] *These costs which were presented in Part One, Appendix C.*

The second step is to illustrate the effect of changing a capital item by a given percentage. The capital cost items which have been included in the analysis are those which have the greatest potential for variability. The percentage of variation assumed is what would be expected in an extreme case. For instance, if the capital cost of initial carbon fill increased by 50 percent either due to a price increase or to the quantity of carbon needed, the effect would be an increase of slightly more than $1 per million gallons of water treated or a percentage change of 1.2 percent. In Table C-31, cost of the initial carbon fill and the regeneration facility would not be expected to change in either direction by more than 50 percent while additional filtration capacity could increase because of site specific reasons by as much as 200 percent.

In addition to varying individual capital items, amortization rates of total capital costs have also been varied to account for possible differences in interest rates or useful lives of capital equipment.

The third step is to vary the significant operating costs to show their effect on total cost. For instance, if the cost of replacing carbon after regeneration losses increased by 50 percent over the base case, the total cost per million gallons of water treated would increase by $5.90 to a total of approximately $130. This represents a 4.8 percent increase over the base case.

While the analysis shows the impact of changing one component while holding everything else constant, it is easily possible to assess the changes that occur when two items are varied. Using Table C-31 again as an example: if carbon replacement costs and furnace fuel costs both decreased by 50 percent, the change in cost per million gallons would be $9.90 per million gallons or $5.90 plus $4.00. The percentage change over the base cost of $120 per million gallons would be 8.2 percent or 4.8 plus 3.3.

General Findings

The most significant conclusion is that, in general, the changes have less than a ten percent effect on total costs. The effect of changing various components can range, however, from having a negligible impact upon total cost to causing an increase of over 200 percent. Also, changes in cost of capital items generally have decreasing effects as plant size increases. The exceptions to this are costs such as initial carbon fill that vary on a one to one basis with production. Changes in operating cost items, on the other hand, generally assume more importance as plant size increases.

The relative impact of changing the costs of individual line items in operating costs differs among the size categories. Therefore, the items most appropriate for cost control emphasis will differ among plants of various sizes. For GAC use, at a 6.7 MGD plant, variations in the five operating cost components all have about the same effect. However, at a 455 MGD plant, management should be more concerned about fuel costs, for instance, than about the labor costs associated with the addition of extra personnel to operate a regeneration furnace.

The impacts of changing individual cost items by treatment are described in the following section. A concluding section summarizes those items with the highest impact for each treatment.

Individual Treatment Analyses

GRANULAR ACTIVATED CARBON ADSORPTION (REPLACING MIXED MEDIA WITH CARBON)

The major capital items subject to variability when replacing mixed media in the filter bed with carbon are:

initial carbon fill, the regeneration facility, and additional filter capacity. Table C-31 shows a decreasing trend in the impact of capital costs on total cost as plant size increases. The exception to the general trend is the cost for initial carbon fill for which there are no economies of scale; the necessary amount of carbon increases directly with plant size. The impact of changes in the cost of equipment such as regeneration facilities and additional filtration capacity is smaller for larger sized plants since the capital cost component is a smaller percentage of the total cost per million gallons of water treated. For a 6.7 MGD plant, capital costs account for $44 out of $120 of total costs, or 37 percent; for a 485.3 MGD plant, capital costs only contribute $11 out of $30 per MGD, or 28 percent.

Treatment costs are also sensitive to the amortization rate used. If the rate increases from 10 to 16 percent, this change has an impact on overall costs that is larger than any of the changes in individual capital components. The impact on a percentage basis decreases with increasing plant size reflecting the smaller contribution of capital costs to total costs for larger plants.

The significance of the impact of individual operating cost items depends on whether they are directly proportional to production. For a 6.7 MGD plant, a 50 percent increase in carbon replacement costs (which are directly proportional to production) causes an increase in the total cost of 4.2 percent. The same increase in carbon replacement costs for a 485 MGD plant causes a 15.1 percent change in costs. On the other hand, the labor to operate a furnace does not increase significantly with production. The percentage impact of changes in labor cost are smaller for larger sized plants.

Table C-31 summarizes the impact on total cost of changes in capital and operating costs for three sizes of water systems.

| | | |

GRANULAR ACTIVATED CARBON ADSORPTION (FOLLOWING CONVENTIONAL FILTRATION)

Many of the trends that are present in the previous analysis are also present in GAC adsorption following filtration. In this use of GAC, the major capital items subject to variability include the cost of initial carbon fill, modification of hydraulics, contactors, and regeneration furnaces. As can be seen in Table C-33, there are economies of scale in modifying hydraulics and in adding regeneration furnaces that reduce the impact on larger systems of a given percentage change in capital costs. While a change of 100 percent in the cost of modifying the hydraulics at a 0.7 MGD plant raises the cost of treating water by 17.0 percent, the same percentage change for a 465 MGD plant only increases the cost by 7.2 percent. Contactors, however, do not exhibit the same economies of scale since they consist of multiple numbers of a specified unit size.

The rate at which capital costs are amortized can have a significant effect on the cost of treated water. At a 465 MGD plant, for example, every percentage point increase in the rate causes an increase of over 4 percent in the cost of treated water.

The operating costs most subject to variability are: adsorber operation, labor for regeneration furnace operation, fuel costs and carbon replacement. The importance of controlling operating costs that vary directly with production of larger sized plants is demonstrated in Table C-33. A doubling of furnace fuel costs and a 50 percent increase in carbon replacement only increase total costs by 5.5 and 4.0 percent, respectively, for a 0.7 MGD plant. However, they increase the cost by 10.8 and 10.4 percent for a 465 MGD plant. Changes in cost that are basically fixed across size categories such as the labor involved in furnace operation are almost negligible for the largest sized plant.

[redacted]

OZONE PLUS A CHLORAMINE RESIDUAL

The application of ozone is a capital intensive process which requires significant equipment expenditures for ozonators and contactors. Variations in these capital costs can cause major changes in the cost of water treated. A change of 50 percent in capital costs for a 6.7 MGD plant (Table C-33) will alter the cost per million gallons by $0.00 or a change of about 32 percent. Changes in amortization rates also can alter the cost by a significant percentage.

The most significant operating cost is the electricity needed to generate ozone. Changes in electricity costs have greater and greater impact as system size increases. For example, a 200% increase in electricity costs changes the total cost for a 6.7 MGD plant by 20.0 percent. The same increase for electricity raises the total cost for a 455.3 MGD plant by 59.3 percent.

In examining the possible variability of ozone costs it should be noted that ozone as a treatment is, in total, less than 25% as expensive as carbon adsorption.

CHLORINE DIOXIDE

Variations in capital cost for chlorine dioxide treatment have only a slight impact on the cost of treated water. An increase of 500 percent in capital equipment for a 6.7 MGD plant only increases the cost of treated water by 22.5 percent. For a 455.3 MGD (Table C-34) plant there is no measurable increase in cost. Since capital costs play such a small role in chlorine dioxide treatment, variations in the amortization rate are also insignificant.

The most significant variable in chlorine dioxide treatment is the cost of the sodium chlorite needed to generate chlorine dioxide. If costs increase from the base case by 500% either through price or dosage increases, the effect is to raise costs by over 200% in all size categories.

| | | |

TABLE C-39

[illegible]

[illegible]	[illegible]			[illegible]			[illegible]		
[illegible]	[illegible]			[illegible]			[illegible]		
[illegible]	[illegible]			[illegible]			[illegible]		
[illegible]	[illegible]			[illegible]			[illegible]		
	[illegible]	[illegible]		[illegible]	[illegible]		[illegible]	[illegible]	
[illegible]									
[illegible]									
[illegible]							

AMMONIA AND CHLORINE

The use of ammonia and chlorine is the least cost method for controlling the formation of trihalomethanes. However, the total cost is sensitive to changes in both capital and operating costs. A 500 percent increase in total capital costs causes a 53 percent change in the total cost for a 6.7 MGD plant. The same increase has only an 8.3 percent impact on the cost of treated water for the largest size plant. Conversely, a change in the cost of chlorine at a 6.7 MGD plant of 50 percent causes only a 13 percent change in total cost. For the larger system, however, a 50 percent chlorine increase changes the total cost by 33 percent.

Summary Of Most Significant Cost Items

The sensitivity analyses have shown the effects of changing major line items in the cost assumptions in each of the treatments available for reducing organic contaminants. The percentage changes represent what would be considered a worst case situation. The items that have been tested are the ones that are likely to differ from system to system and/or could have a significant impact on cost.

The table below lists the items for each treatment and plant size which have the greatest impact on the cost of adding the treatment. The numbers in parentheses are the percentage increases in the total cost.

The general trend in the results presented in the earlier discussions show that for carbon adsorption, capital cost variations play less of a role as one moves to larger treatment plants. For chlorine dioxide treatment, capital costs

| | | |

Table C-59

SUMMARY OF MOST SIGNIFICANT COST ITEMS

Plant Size	Treatment				
	GAC Adsorption (Replace Media)	GAC Adsorption Following Filtration	Ozonation	Chlorine Dioxide	Chlorine + Ammonia
6.7 MGD	Amortization Rate	Amortization Rate	Amortization Rate	Sodium Chlorite	System Capital
% Increase	(80.6)	(27.3)	(40.6)	(221.6)	(88.3)
67.0 MGD	Amortization Rate	Amortization Rate	Amortization Rate	Sodium Chlorite	Chlorine Costs
% Increase	(15.8)	(21.7)	(84.8)	(382.7)	(33.8)
465.3 MGD	Amortization Rate	Amortization Rate	Amortization Rate	Sodium Chlorite	Chlorine Costs
% Increase	(24.1)	(18.1)	(46.1)	(343.3)	(33.3)

and possible variations are not significant, while operating costs play a larger role. The relative importance of capital costs in ozonation to overall costs holds constant throughout size categories. Capital cost variations for chlorine and ammonia treatment are significant for small plants but operating costs assume more importance for larger plants.

The results of the analysis indicate that the treatment with largest potential for variability from the costs developed in the base case is chlorine dioxide treatment. The worst case analysis shows that the costs of sodium chlorite could be as much as 300% higher than the base analysis for some systems. This is not because of uncertainty about unit sodium chlorite costs, but because

the necessary dosage for treatment could be quite variable. The cost of ozone treatment is also likely to vary from plant to plant because of different dosages required for effective disinfection.

In conclusion, this analysis has illustrated that the cost of changing to ozone or chlorine dioxide can be substantially higher than the base case for some systems, and that the cost for the use of GAC will vary less than 20 percent for most systems. The implications for the base case estimates are that they do accurately represent an average level of expenditures; however, for certain treatments the range of variability is high, where as for others it is relatively low.

D

Appendix D

Regulatory Compliance Strategies

APPENDIX D

Regulatory Compliance Strategies

As discussed in the main body of the paper, water systems which exceed a specified trihalomethane level have three major options available to satisfy the regulatory standard--modifying chlorination or other treatment procedures, changing disinfectants, and adding an adsorbent.[1] The calculation of cost estimates for a specific THM regulation requires estimating the number of systems which are likely to select each of these three treatment strategies to comply with the regulation.

Since there is no empirical method for pre-determining the choice which will be made by each affected water system, a more probabilistic and structured approach was necessary. The approach chosen is a step-by-step procedure which can be tracked easily and modified as new information becomes available. A logical sequence of decision points was designed to distribute the systems covered by the regulation according to the most likely path they would follow. The decision made at each point is consistent with certain criteria. The criteria are based upon:

- the treatments currently used: if a system does not chlorinate it will not be affected by a THM regulation, and therefore will require no new treatment

[1] *The category of adding an adsorbent includes a small percentage of systems adding both an adsorbent and a coagulation/sedimentation treatment process.*

- water source used: if a system uses surface water as its primary source, it is more likely to exceed a given level of THM contamination. Hence, the number of water systems using water from ground or surface sources affects the number of systems which will exceed a given level and therefore require treatment

- degree to which water quality exceeds MCL: if the presence of THM is only slightly in excess of the standard, then minimal modifications to procedures will be adequate for compliance. As the level of contamination increases, a system must consider more significant (and costly) treatment techniques

- economic considerations: the presumption is that systems will adopt the least cost treatment strategy which satisfies the regulation

- treatment effectiveness: the presence of THM above certain levels can probably be controlled only by the use of adsorbents. This is because of the likelihood that high disinfectant demand water cannot be adequately disinfected without generating a considerable amount of by-products of unknown hazards. Consequently, those few systems with a very high level of THM are likely to require the addition of the most costly treatment.

The estimates presented below are the result of considering these criteria. The primary participants in the evaluation were:

- the technical staff of EPA's Municipal Environmental Research Laboratory (MERL)

- Energy Resources Company

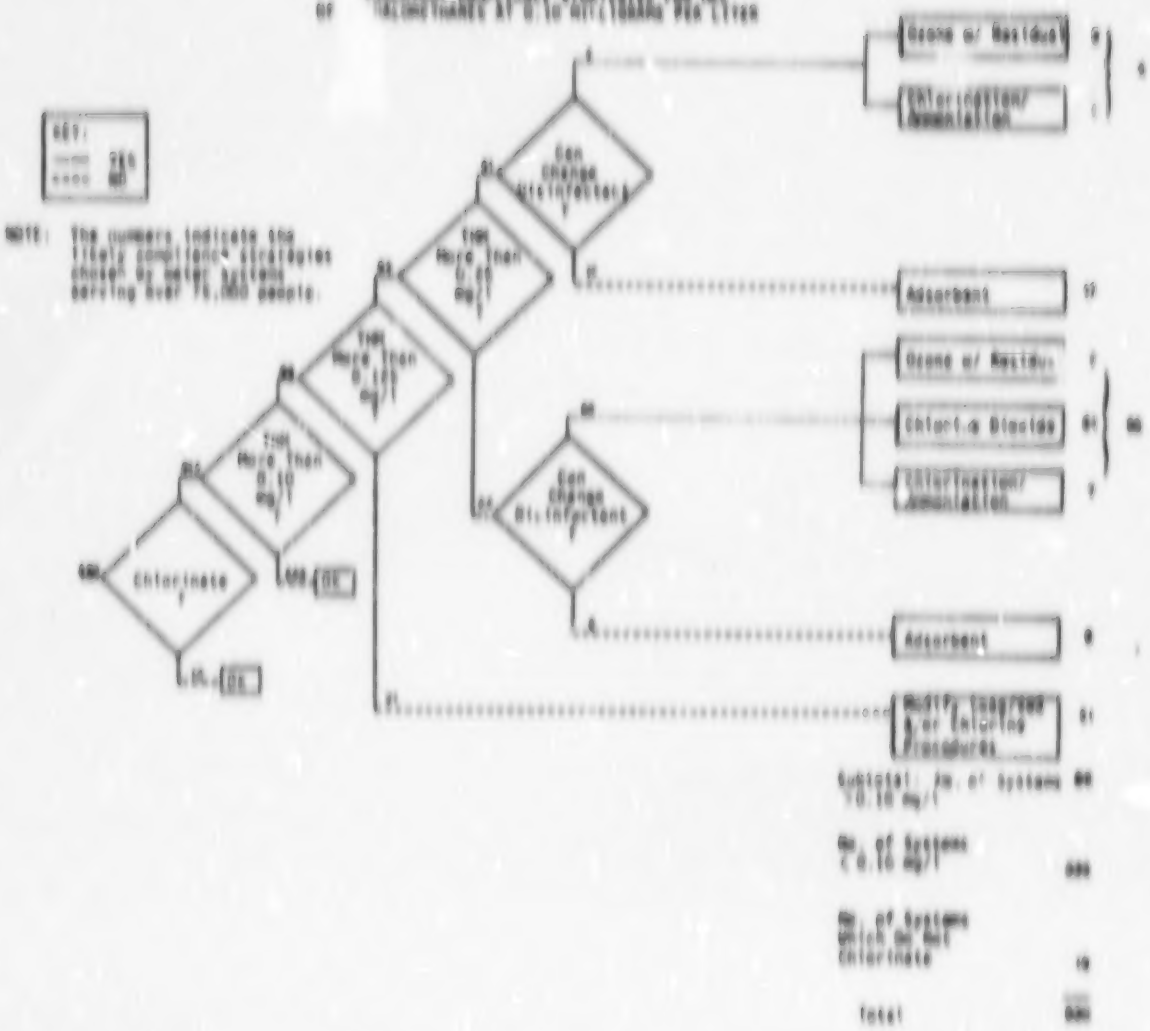
- EPA Water Supply Office staff.

The attached decision tree structure illustrates the paths expected to be followed for compliance with the THM at 0.10 milligrams per liter regulation by each of the 330 water systems which serve more than 75,000 people. Sixty of these systems purchase the majority of their water from other systems which are presumed to provide the treatment. Thus a total of 330 systems may have to add treatments, though 18 of these are excluded since they do not presently chlorinate. Of the remaining 312, some 80 are estimated to have THM levels above 0.10 milligrams per liter and hence would require treatment. The 21 systems which are estimated to exceed the 0.10 milligram level by less than 25 percent are assumed to be able to comply by the least costly method--minor modification of existing chlorination or other procedures.

The remaining 59 systems are split into those above and below a THM level of 0.25 milligrams per liter. Of those estimated to be over the 0.25 level, about 20 percent are assumed to be able to comply by changing disinfectant and the remainder (80 percent) would be required to use an adsorbent to achieve compliance; in these cases, changing disinfectants would not bring the system into compliance with the regulation. As noted previously, the disinfectant demand would be excessive in those instances where high levels of total organic carbon are present. Eighty percent of those below the 0.25 level are assumed to change disinfectant and the remaining 20 percent to use an adsorbent. The results of these treatment selections are that 39 systems would change disinfectants and 26 would use adsorbents as a compliance strategy.

This distribution of selected treatments is used as the basis for the majority of the results presented in the paper and is included to illustrate the methodology.

Exhibit D-1



NOTE: The numbers indicate the likely compliance strategies chosen by water systems serving over 75,000 people.